The Cyclone Global Navigation Satellite System (CYGNSS) – Analysis and Data Assimilation for Tropical Convection

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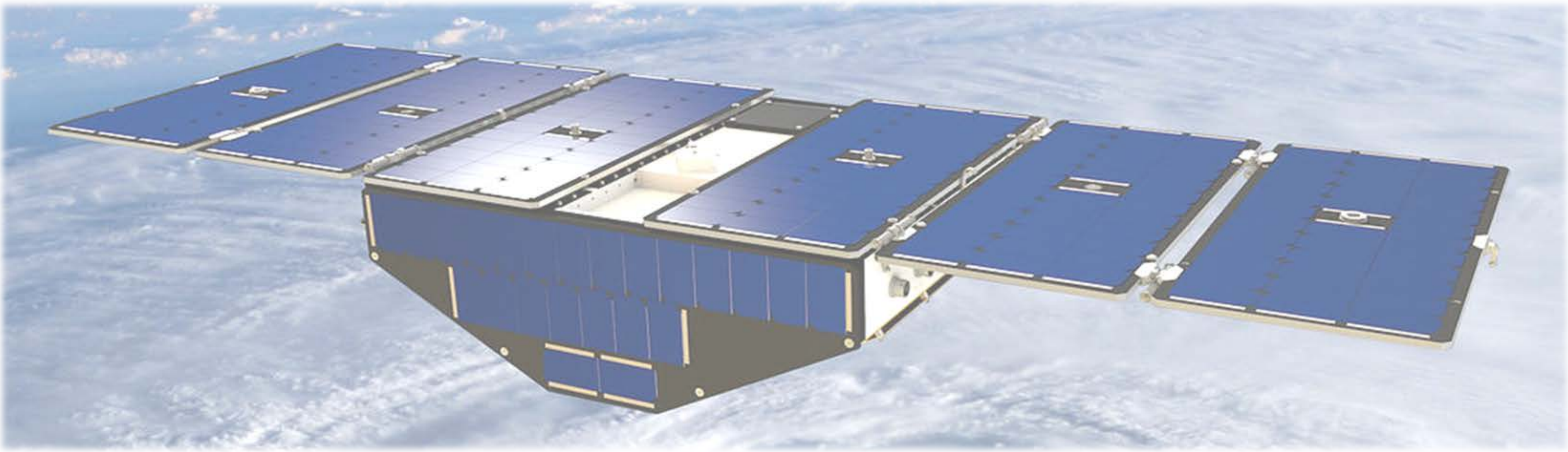
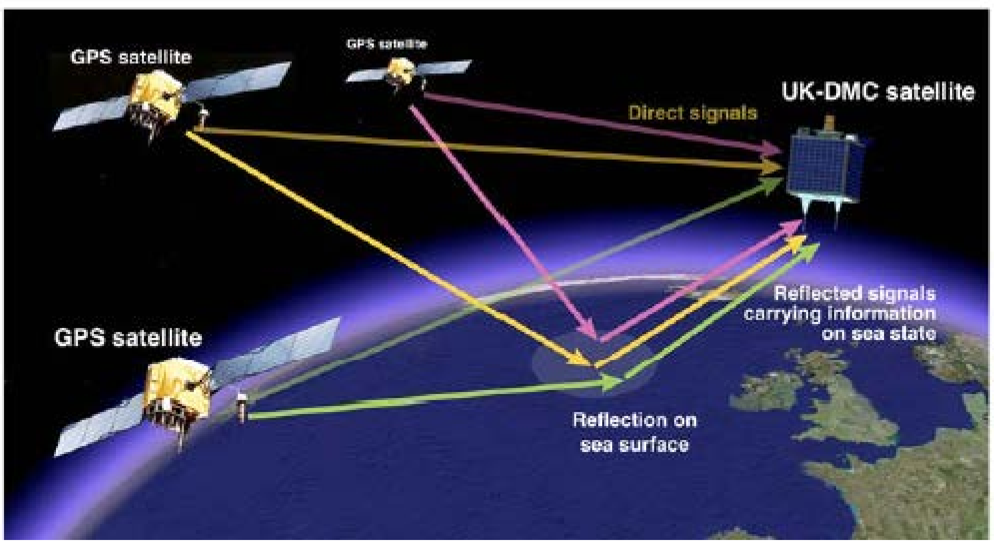
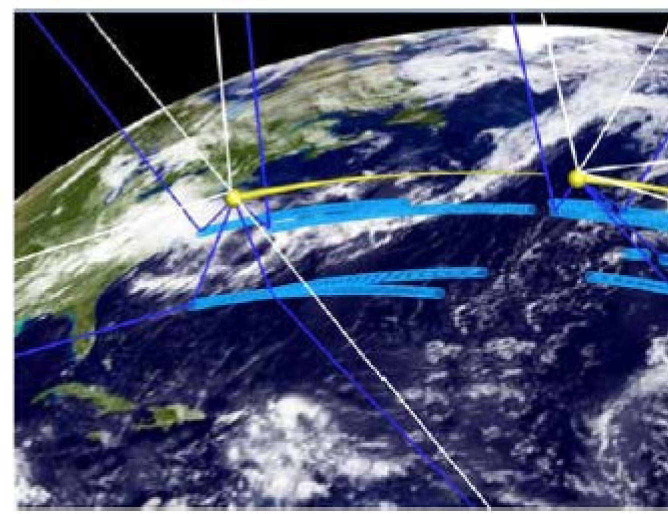


CYGNSS

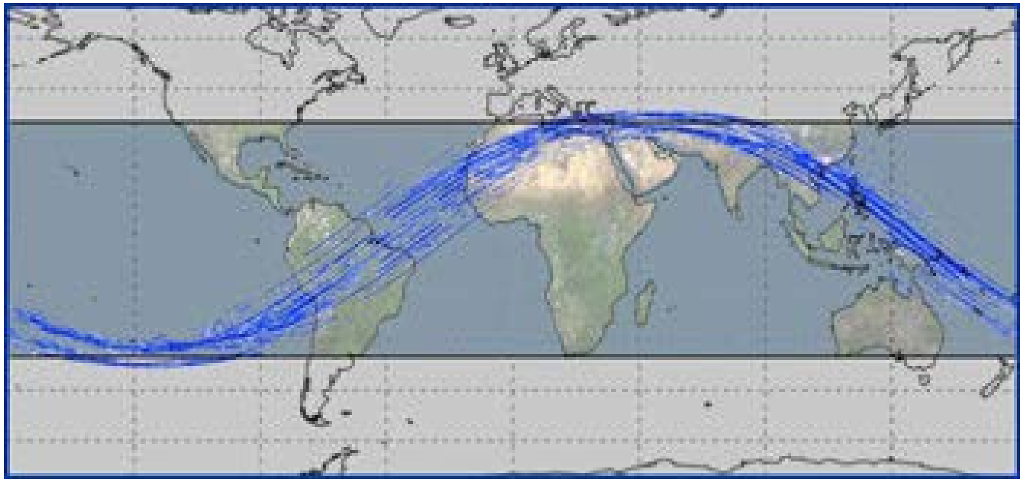
Cyclone Global Navigation Satellite System (CYGNSS): a constellation of 8 micro-satellite observatories launched in November 2016, to measure near-surface oceanic wind speed.
Main goal: To monitor surface wind fields of the Tropical Cyclones' inner core, including regions beneath the intense eye wall and rain bands that could not previously be measured from space; Cover 38°S – 38°N with unprecedented temporal resolution and spatial coverage, under all precipitating conditions
Low flying satellite: Pass over ocean surface more frequently than one large satellite. A median(mean) revisit time of 2.8(7.2) hrs.



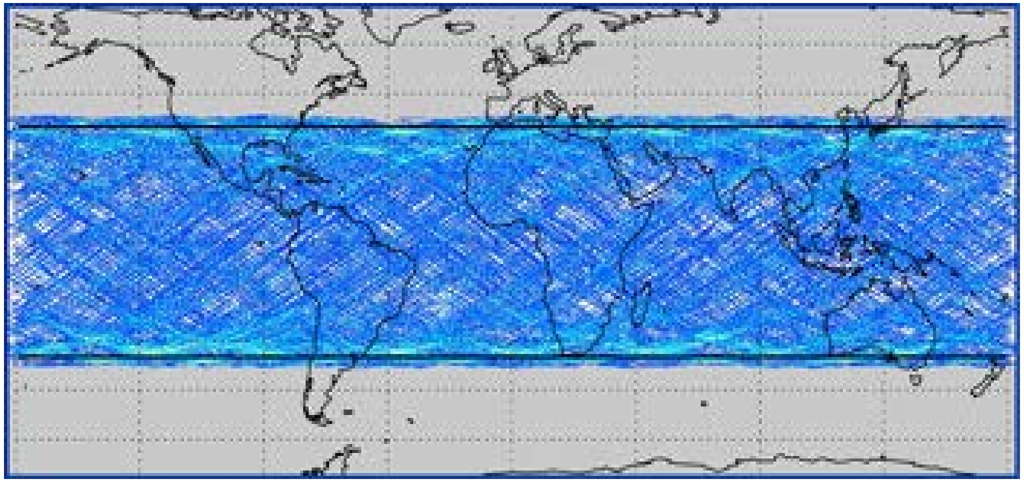


Orbits at an inclination of 35°
4 specular acquisitions per second

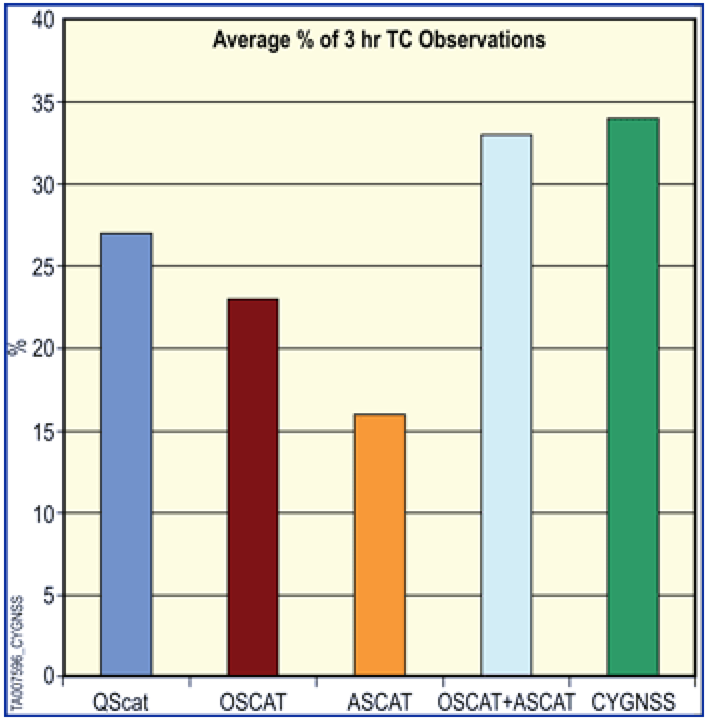
CYGNSS



Ground tracks for 90 minutes from the eight satellites



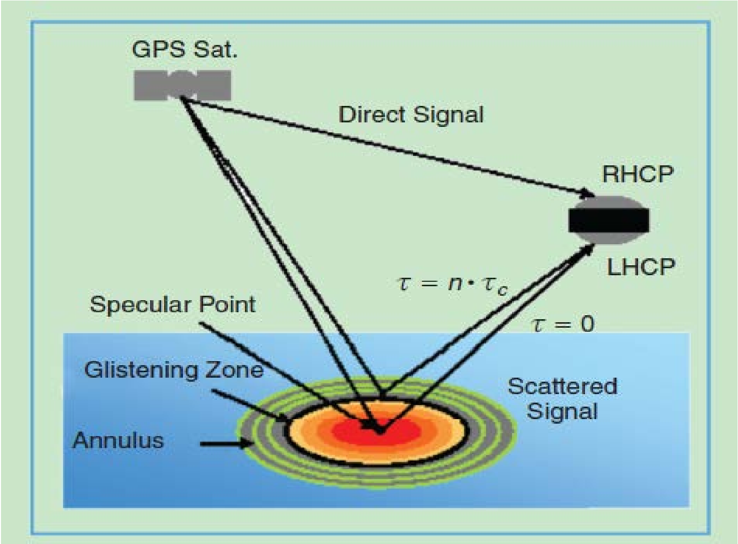
Ground tracks for 24 hours from the eight satellites

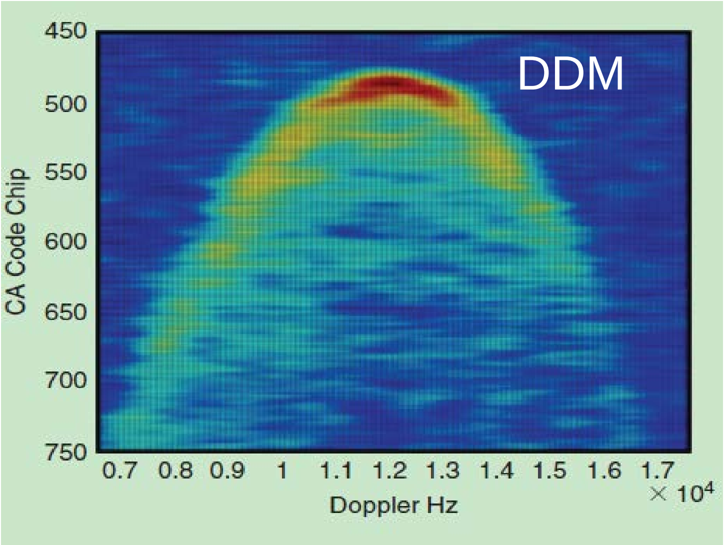


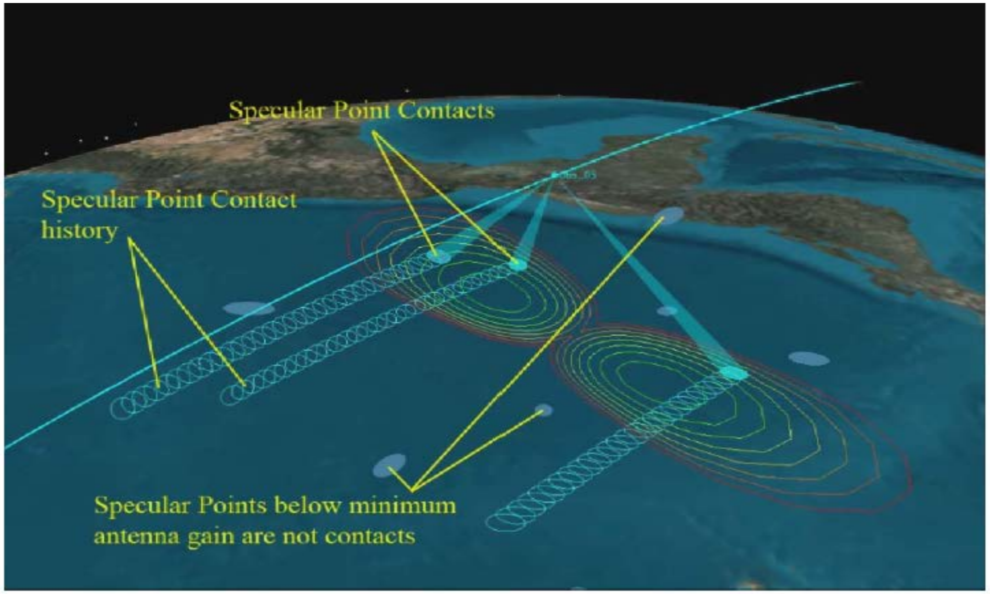
Sampling capacity: the percentages of TC inner core measurement in 3-hour

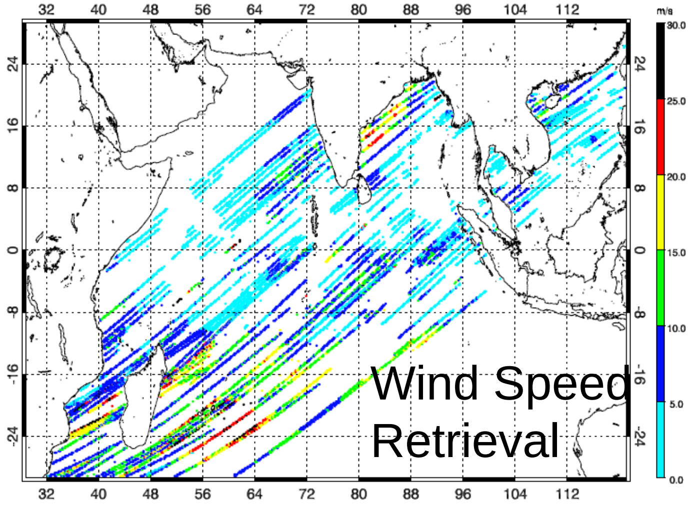
CYGNSS Instrument Definition

Zenith Antenna: Collect GPS direct signal
Nadir Antennas: Collect GPS scattered signal
DMR: Delay Mapping Receiver – Create Delay Doppler Map (DDM)









Two NASA Projects

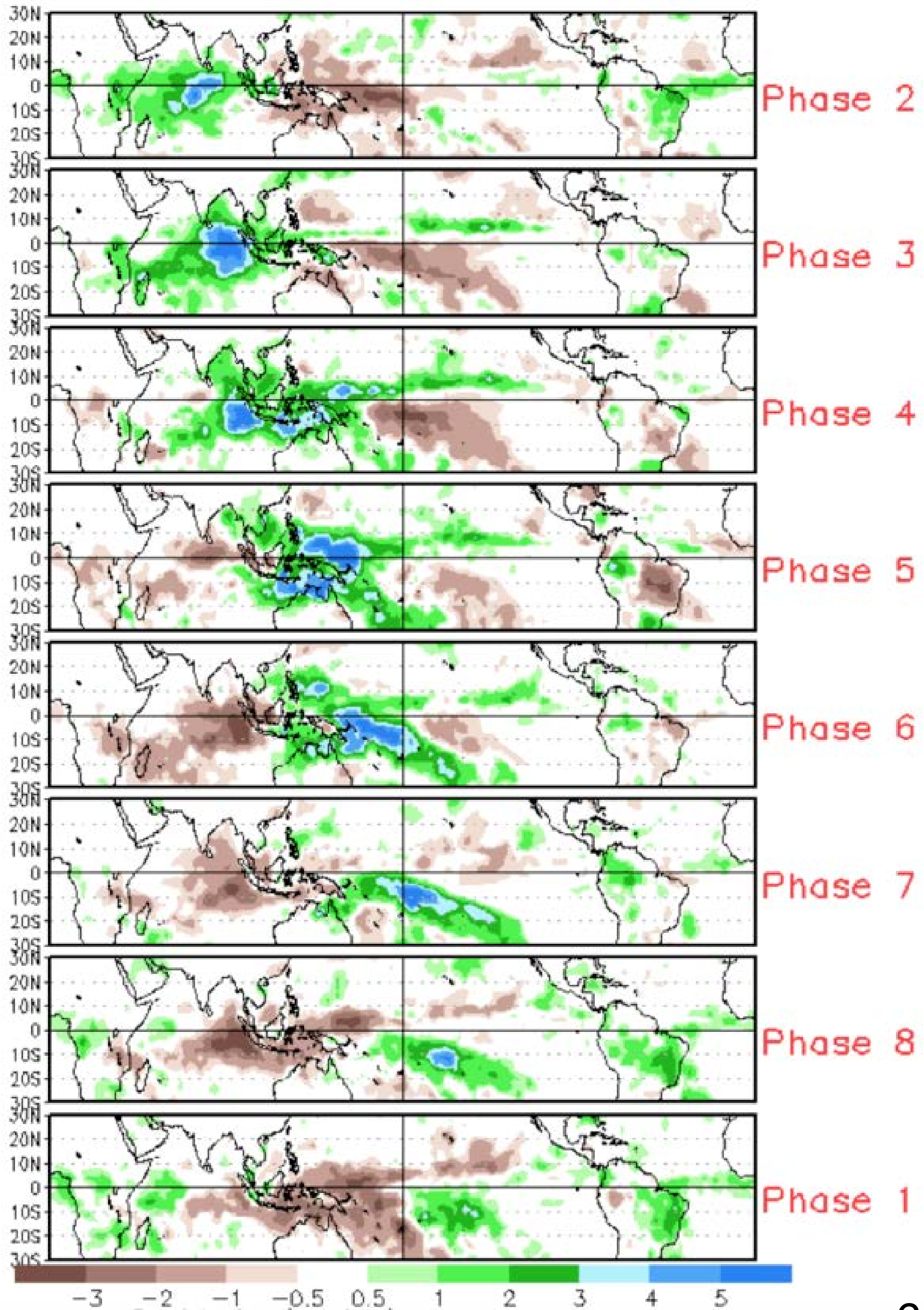
Research goals: To analyze and utilize the high spatial coverage and temporal resolution simulated and real CYGNSS data.

NASA Project #1:
Exploring the utility of the planned CYGNSS mission for investigating the initiation and development of the Madden-Julian Oscillation

- Investigate MJO onset using DYNAMO field campaign observations
- Examine how CYGNSS observe tropical convection under heavy precipitation condition
- Assimilate CYGNSS observation with Observing system simulation experiments (OSSEs)

MJO

- Eastward propagation of regions of enhanced/suppressed precipitation.
- Distinct patterns in low-level and upper level atmospheric anomalies: OLR, upper level velocity potential, upper and lower level wind, 500-hPa height.
- Planetary-scale over equatorial tropical
- Intraseasonal, a period of 30-90 days.
- Modulation of tropical and extratropical precipitation, monsoon systems, ENSO cycle, tropical cyclone activities, and other meteorological and oceanographic phenomena.
- **Challenge:** Lack of high-resolution observations of the many facets of the equatorial tropical atmosphere and ocean
- **DYNAMO and CYGNSS:** To characterize the key feature in wind field anomaly during the MJO



DYNAMO Campaign

Dynamics of the Madden-Julian Oscillation (DYNAMO)
- Goal: To observe the cloud population and evaluate the effects of the air-sea interactions, on both the small and large scale, during a MJO event
- 2011 October, November, and December MJO events.

Intensive instruments:

- Indian Ocean - West Pacific
- Sounding array
- Air-sea fluxes
- Ships and buoys
- Satellite and aircraft data
- Radar network

CYGNSS E2ES

CYGNSS End-to-End Simulator (E2ES):

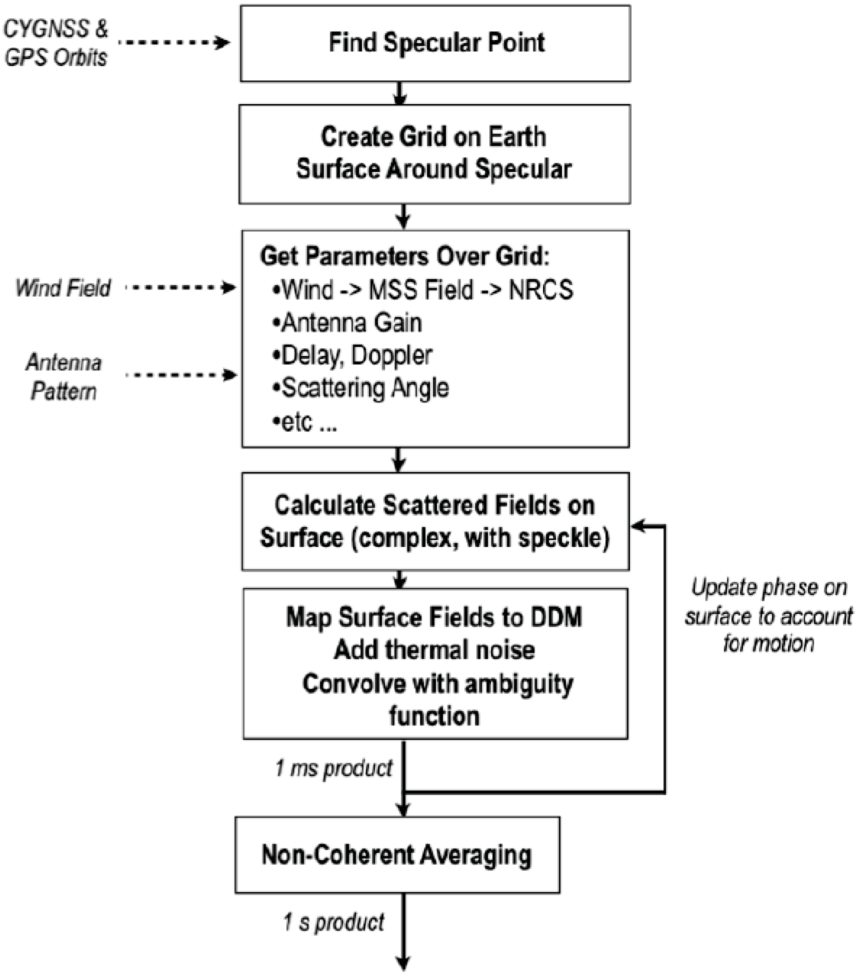
Developed by CYGNSS science team, duplicating the satellites' path patterns and configurations

Generate DDM's ocean scattering using a fine grid around the specular point

Scattering cross-section, combined with the antenna gains, ranges, and transmitted power are used to compute the total scattered power and mapped into delay-Doppler space

Input: Gridded time, location, surface wind, precipitation, ocean conditions (SST, salinity, etc)

Output: L1 DDM
L2 retrieved wind speed 25 km grid.

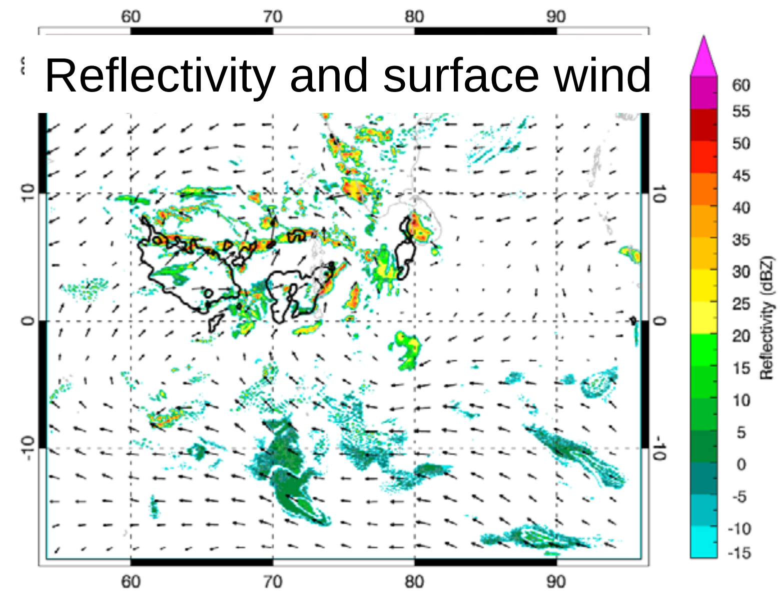


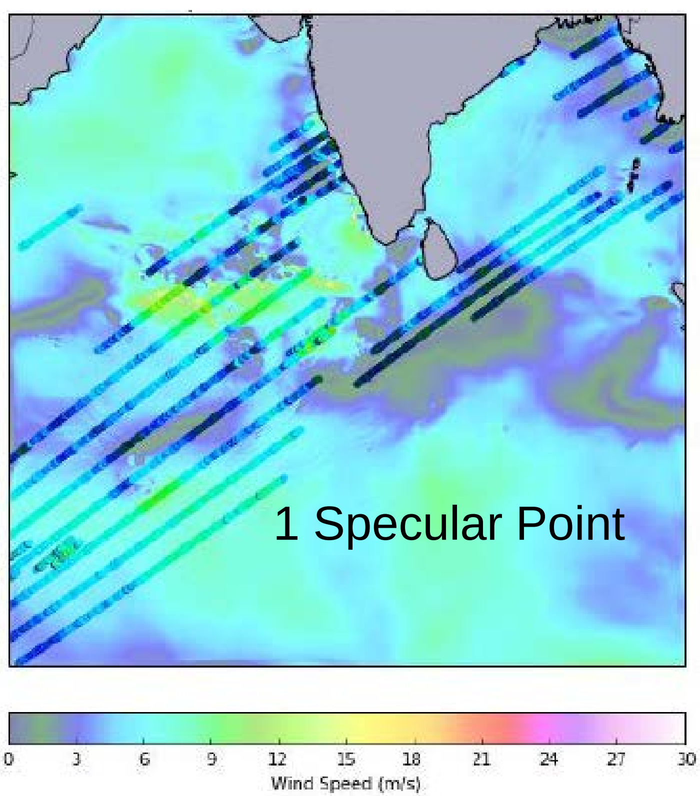
O'Brien (2014): CYGNSS End-to-End Simulator Technical Memo

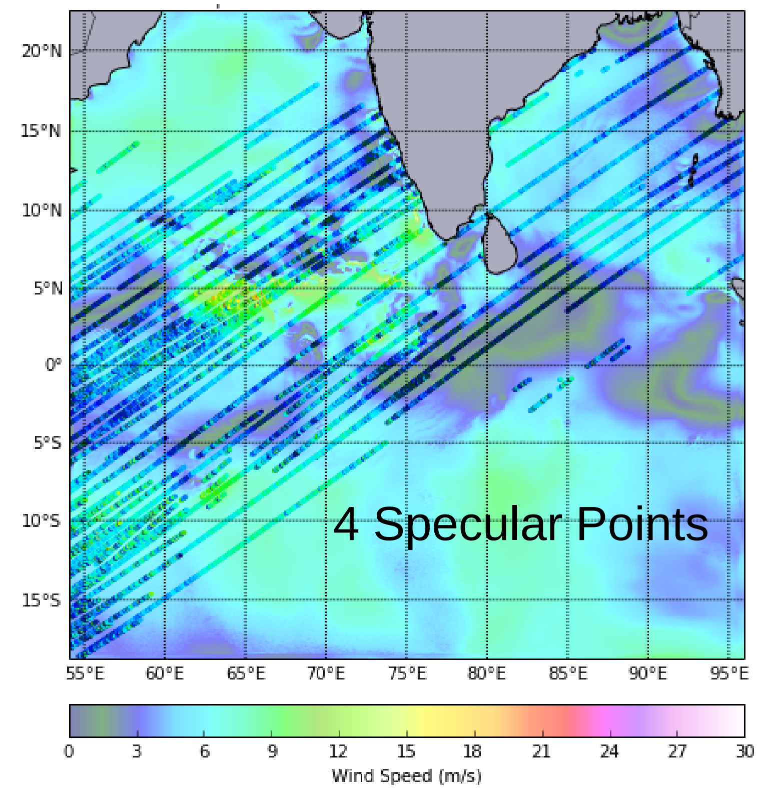
E2ES Case Studies: How CYGNSS Views Convection

9-km resolution WRF simulation
Tropical convection during DYNAMO campaign

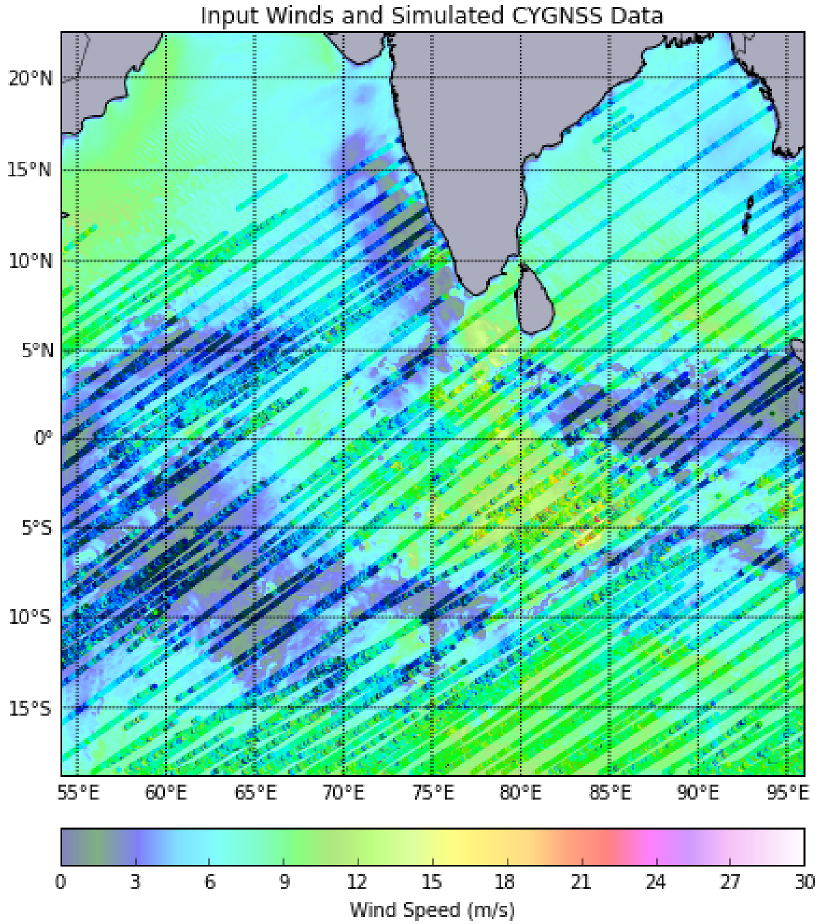
1-s sampling
12 – 14 UTC 26 October 2011



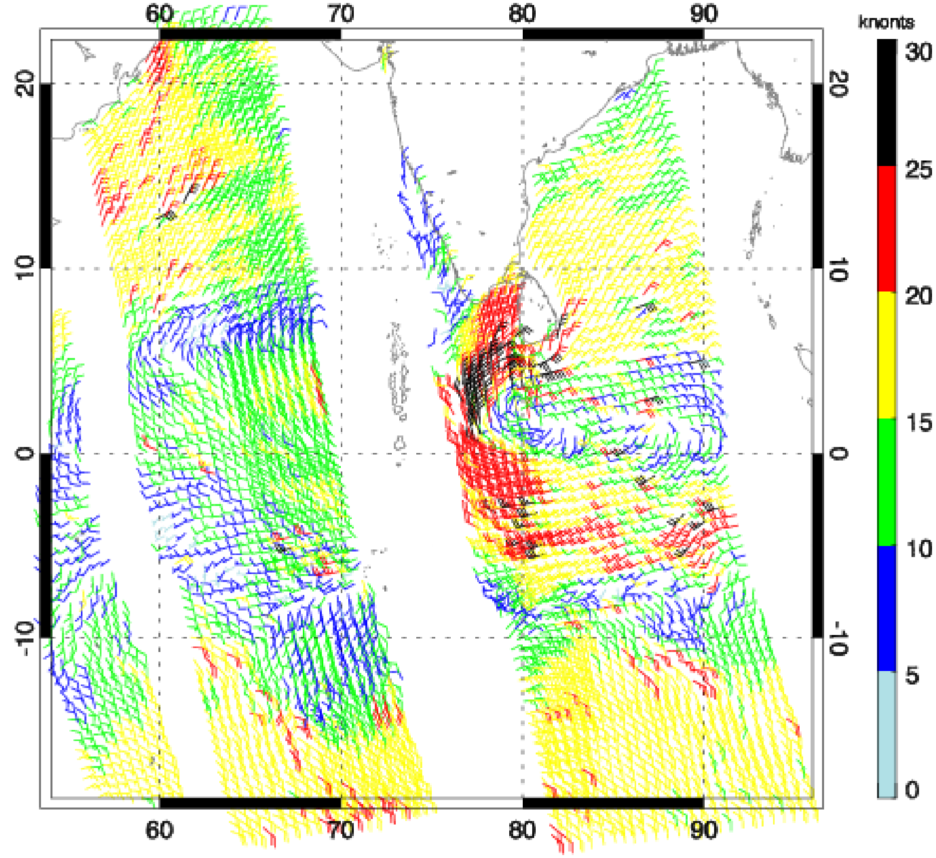




How CYGNSS Views Tropical Convection

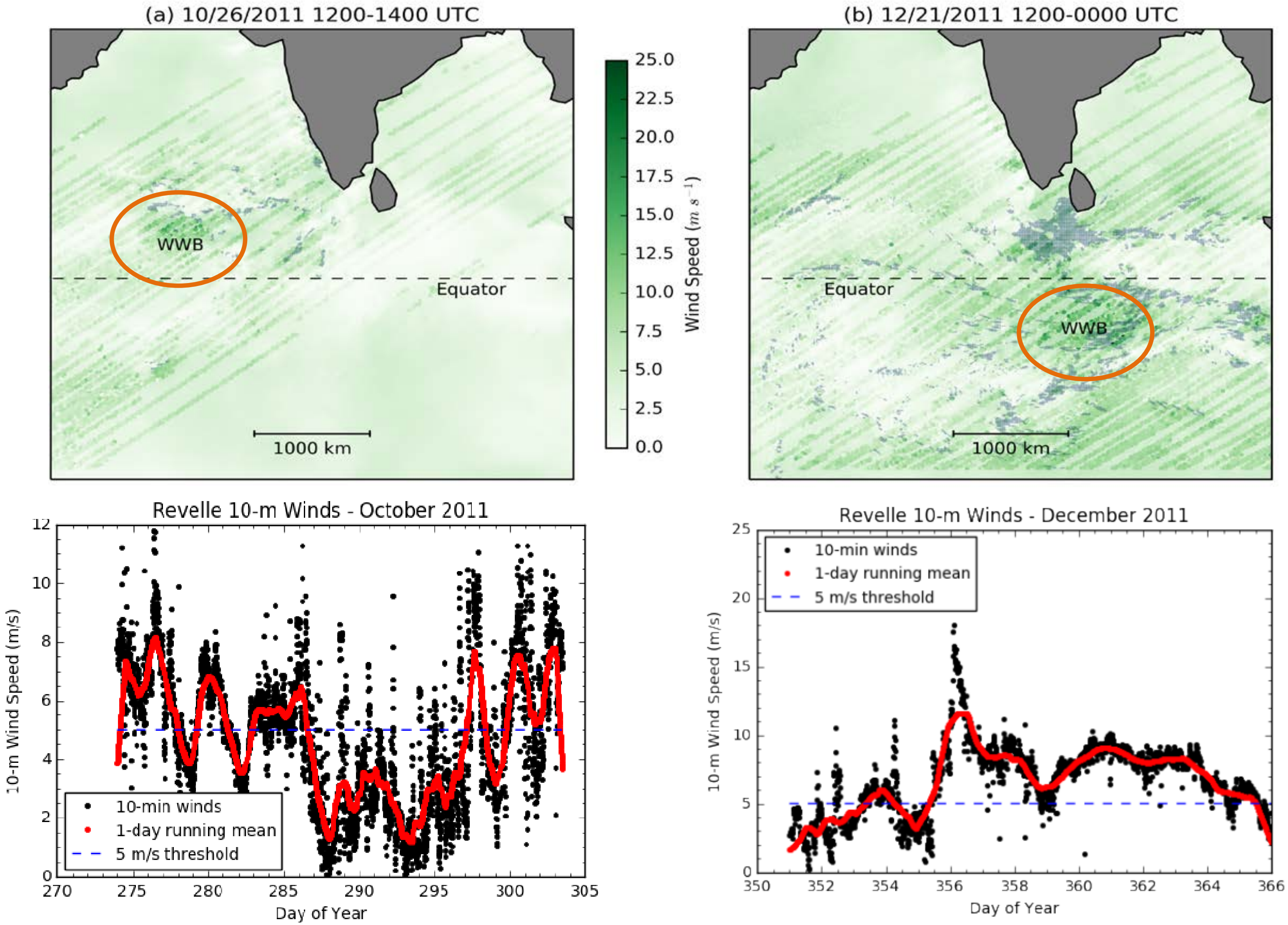


4 specular point
12 UTC 21 to 00 UTC 22 December 2011



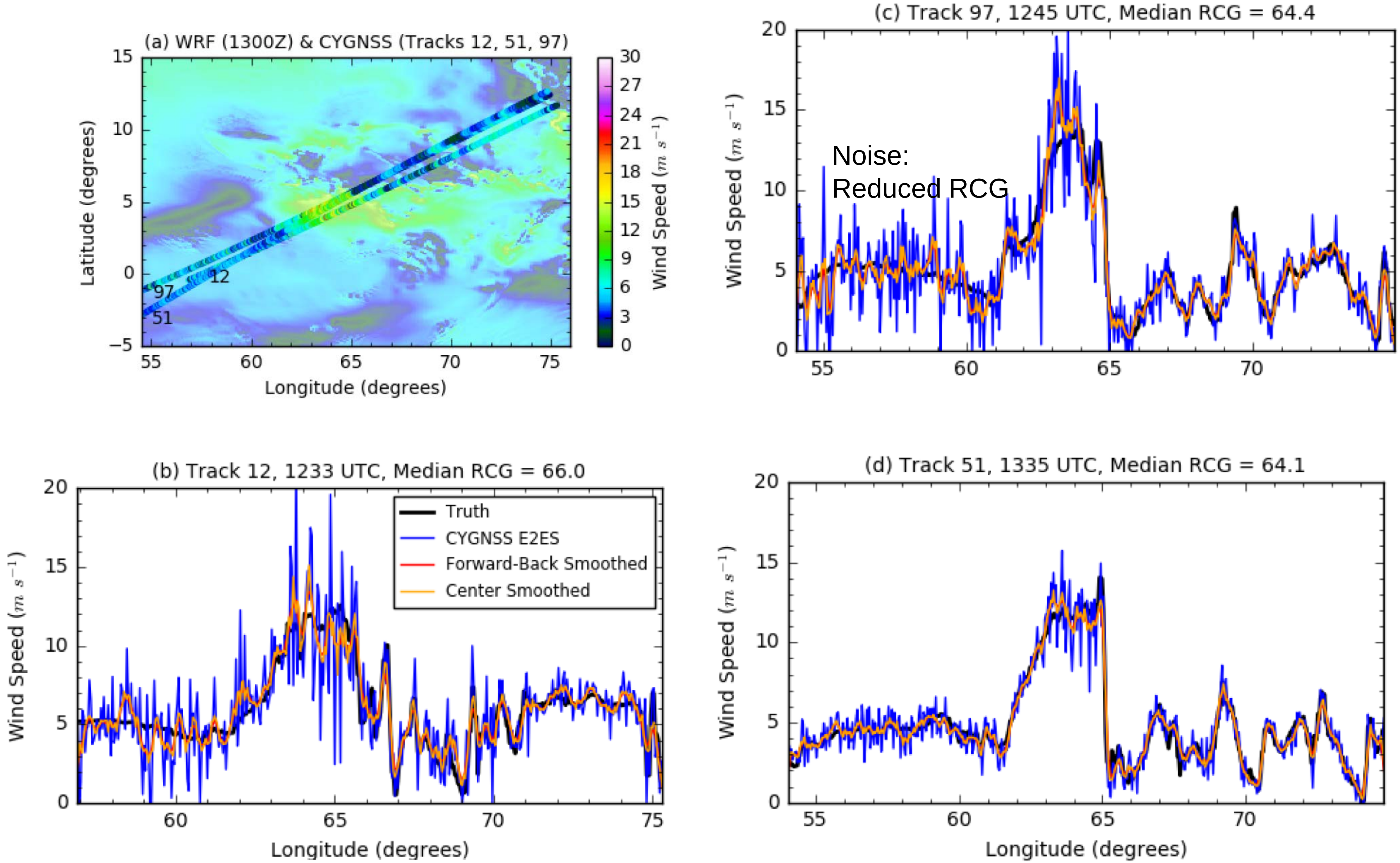
ASCAT/OSCAT wind
15 – 17 UTC 21 December 2011

CYGNSS Observation: WWBs

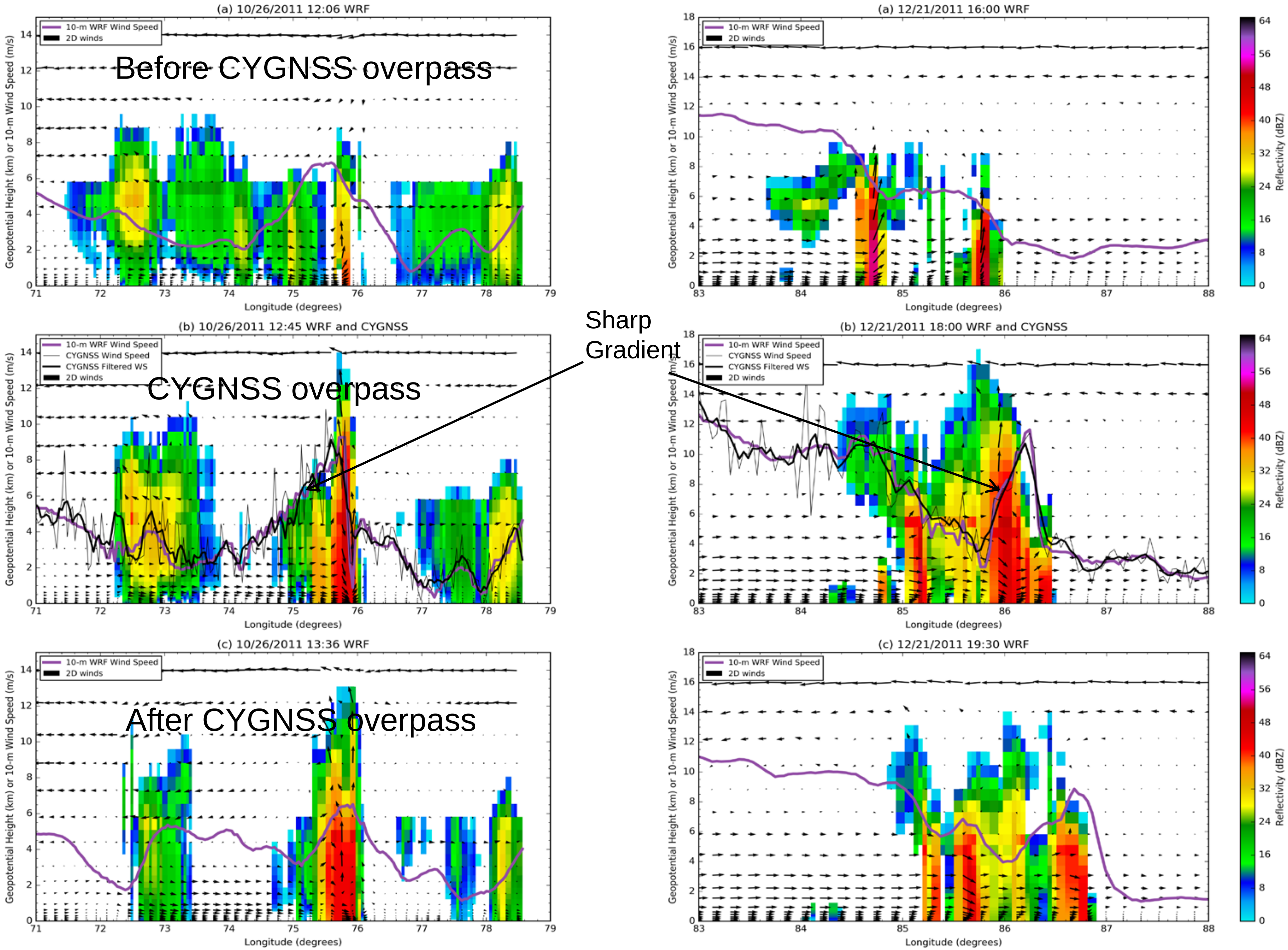


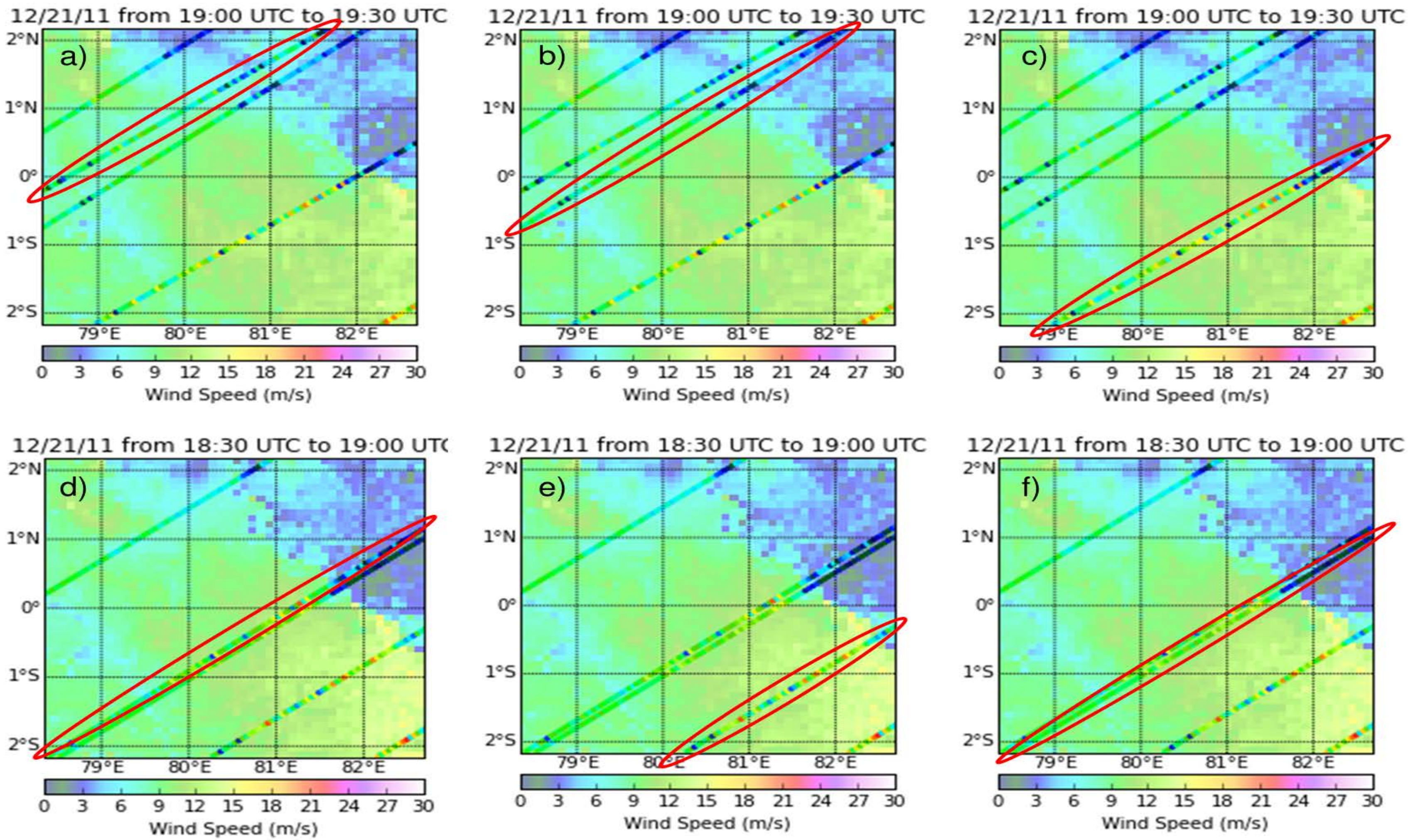
Westerly Wind Burst (WWB): sustained zonal wind over 5m/s for a few days
MJO: Eastward propagation of convective clusters associated with WWB

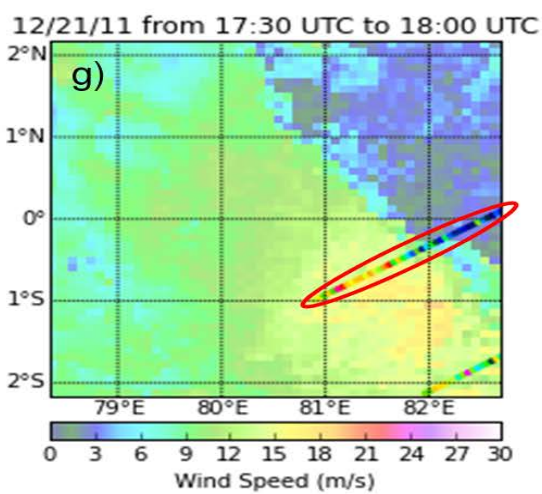
CYGNSS vs. WRF truth wind for WWBs



Convection Along Specular Point Track

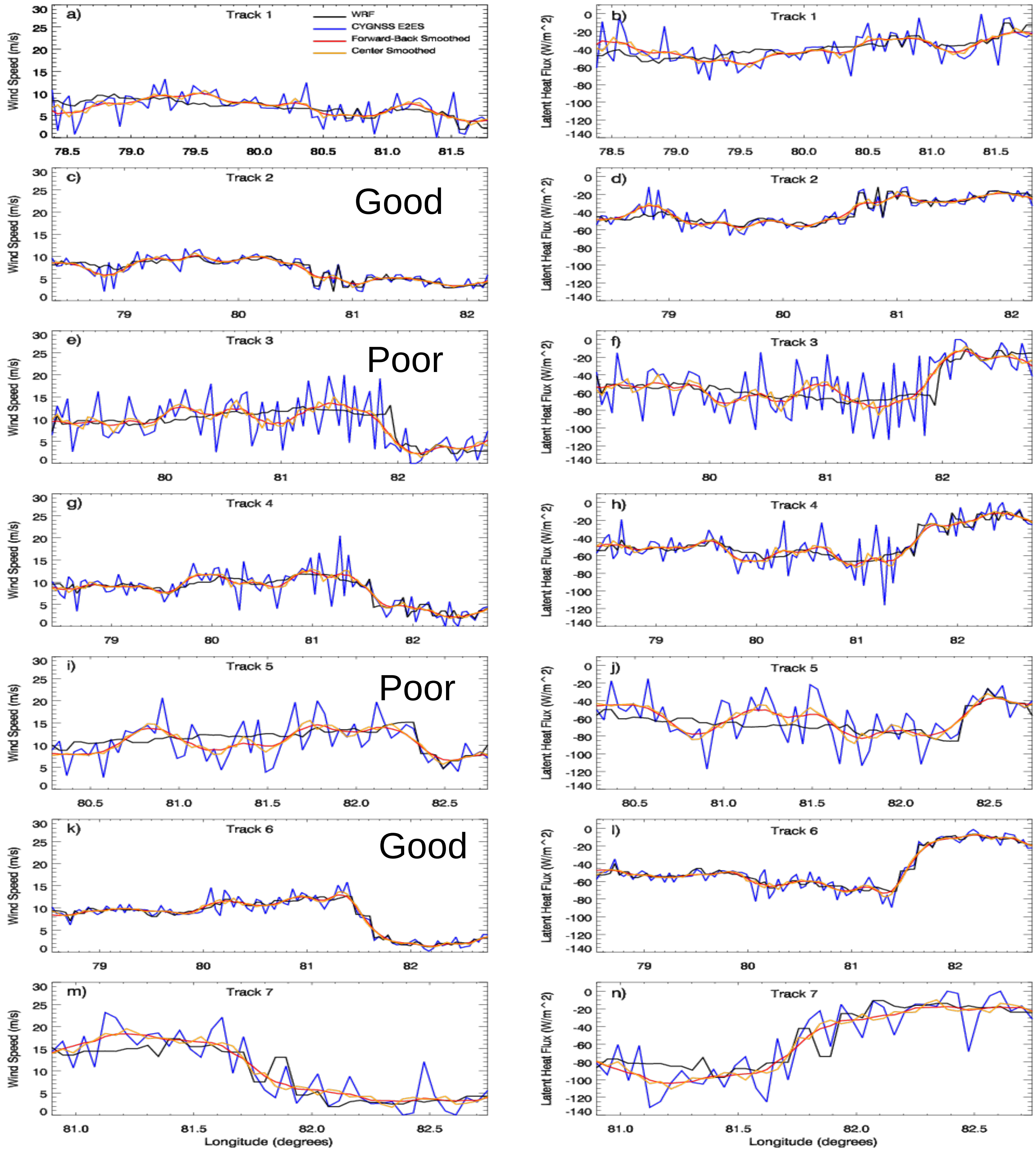






WWB event
30 min WRF input
1730 – 1930 UTC 21 December 2011

Application of CYGNSS wind: Latent Heat Flux Estimate



Strong Wind Gradient

	Simulated	Centered	Fwd-Bk	Mean RCG
Track 1	31.2%	16.5%	16.0%	1.5
Track 2	15.4%	12.5%	11.4%	11.2
Track 3	37.5%	15.8%	13.2%	1.3
Track 4	23.7%	10.3%	9.0%	6.4
Track 5	35.6%	20.0%	17.5%	2.5
Track 6	9.5%	6.1%	5.2%	40.7
Track 7	24.9%	16.2%	14.4%	1.2
RMSE	25.4%	13.9%	12.4%	

Normalized Root Mean Square Error: 25.4%

Centered Smoothing: 13.9%

Forward-Back Smoothing: 12.4%

Research Result on CYGNSS data for NASA Project #1

1. CYGNSS is able to characterize the mesoscale convective variability, such as WWBs and gust fronts, associated with tropical convection during the MJO.
2. CYGNSS has the ability to observe convectively driven winds in heavy precipitation Indicated by the fast-mode E2ES generated data.
3. E2ES was able to produce realistic tracks of CYGNSS specular points using the WRF-based input atmosphere, that demonstrated tradeoffs between RCG and retrieval accuracy.
4. CYGNSS data has natural spatial sparseness in successive specular point tracks do not line up in a spatially contiguous swath like traditional scatterometers. However, counteracting this data sparseness is the more frequent revisit times at a particular location as compared to ASCAT, OSCAT and QuikSCAT.
5. Filtering and/or high RCG(>10 m^{-4}), CYGNSS data be used for air-sea flux estimates within and near convection. For low RCG (<10 m^{-4}), filtering can reduce wind errors by as much as a factor of 2. In general, aggressive filters (forward-back method) perform better than less aggressive ones (centered method) in low-RCG situations.

Hoover et al. 2017: “Use of an End-to-End-Simulator to analyze CYGNSS” submitted to *J. Atmos. Ocean. Tech.*

CYGNSS Data Application: Data Assimilation

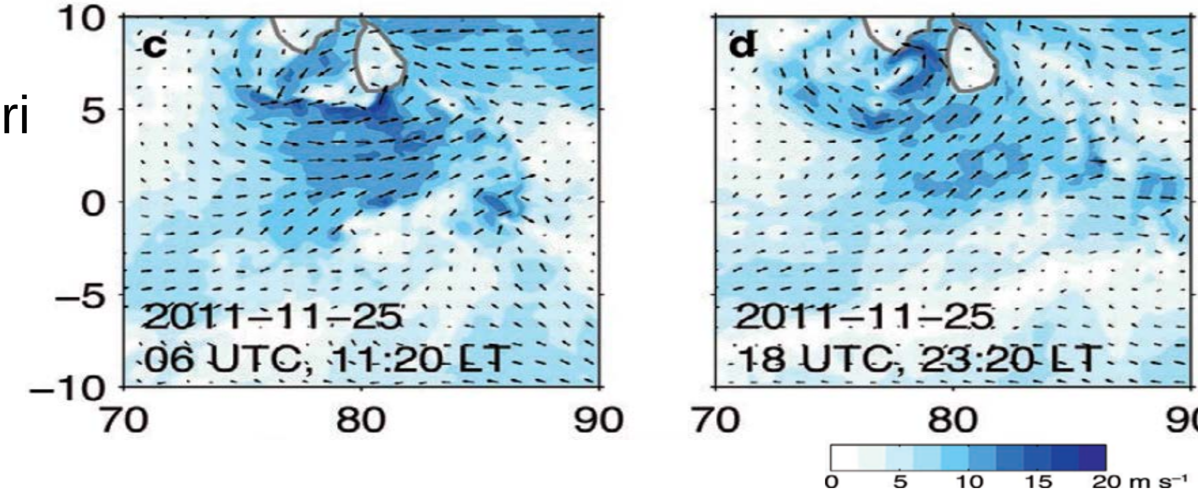
Northern Indian Ocean TS 05A:

Vortex formed on 2011-11-25

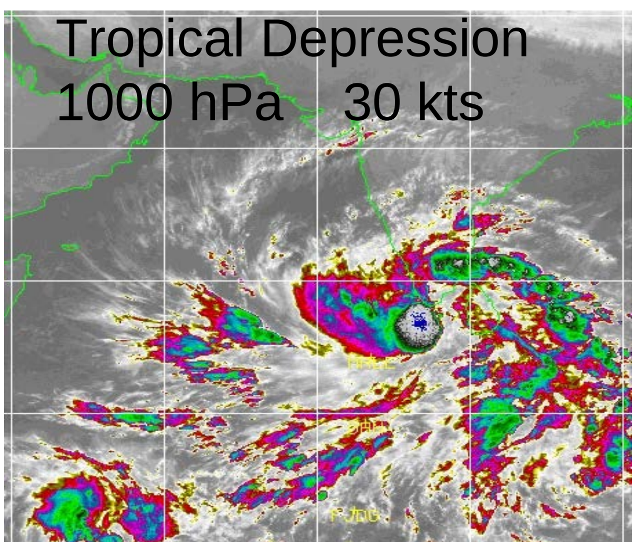
Severe damage along coast of Sri Lanka

Sustained onshore wind >10m/s

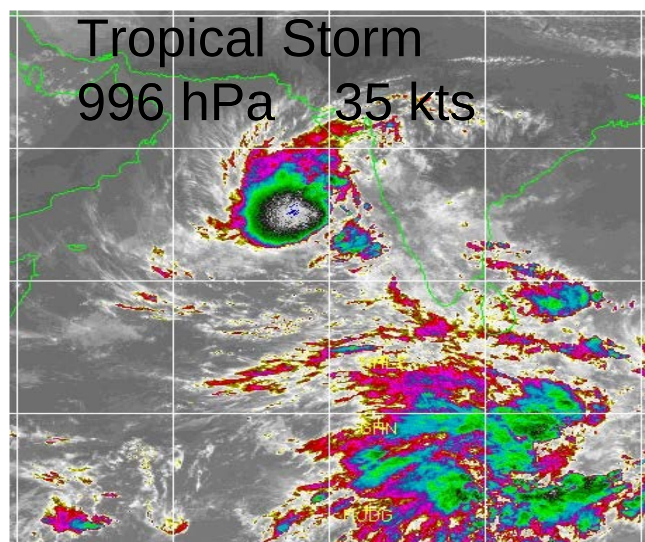
Loss of 33 lives



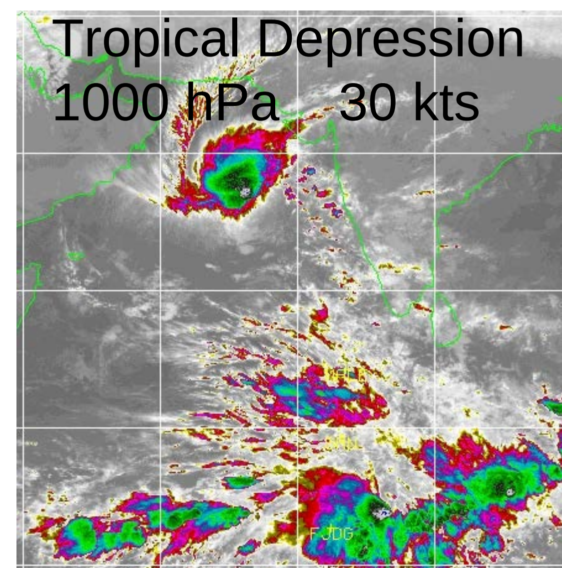
18 UTC 2011-11-25
Tropical Depression
1000 hPa 30 kts



06 UTC 2011-11-28
Tropical Storm
996 hPa 35 kts

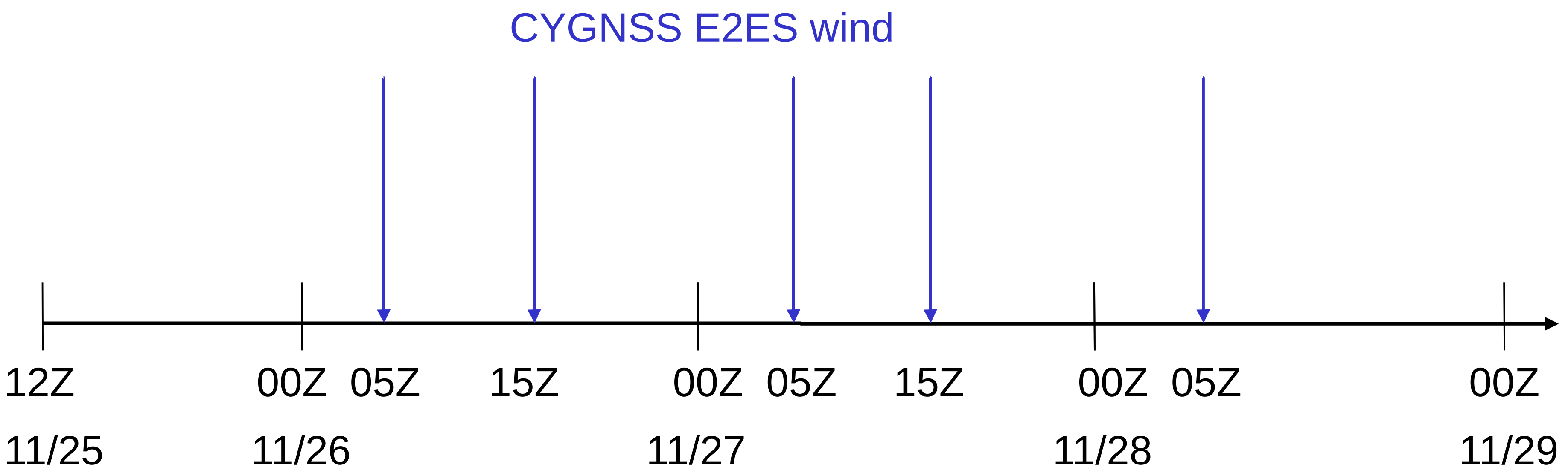


00 UTC 2011-11-29
Tropical Depression
1000 hPa 30 kts



CYGNSS Data Application: Data Assimilation

OSSE: Cycled Data Assimilation for TS 05A 2011-11-25 – 2011-11-29



3 Experiments:

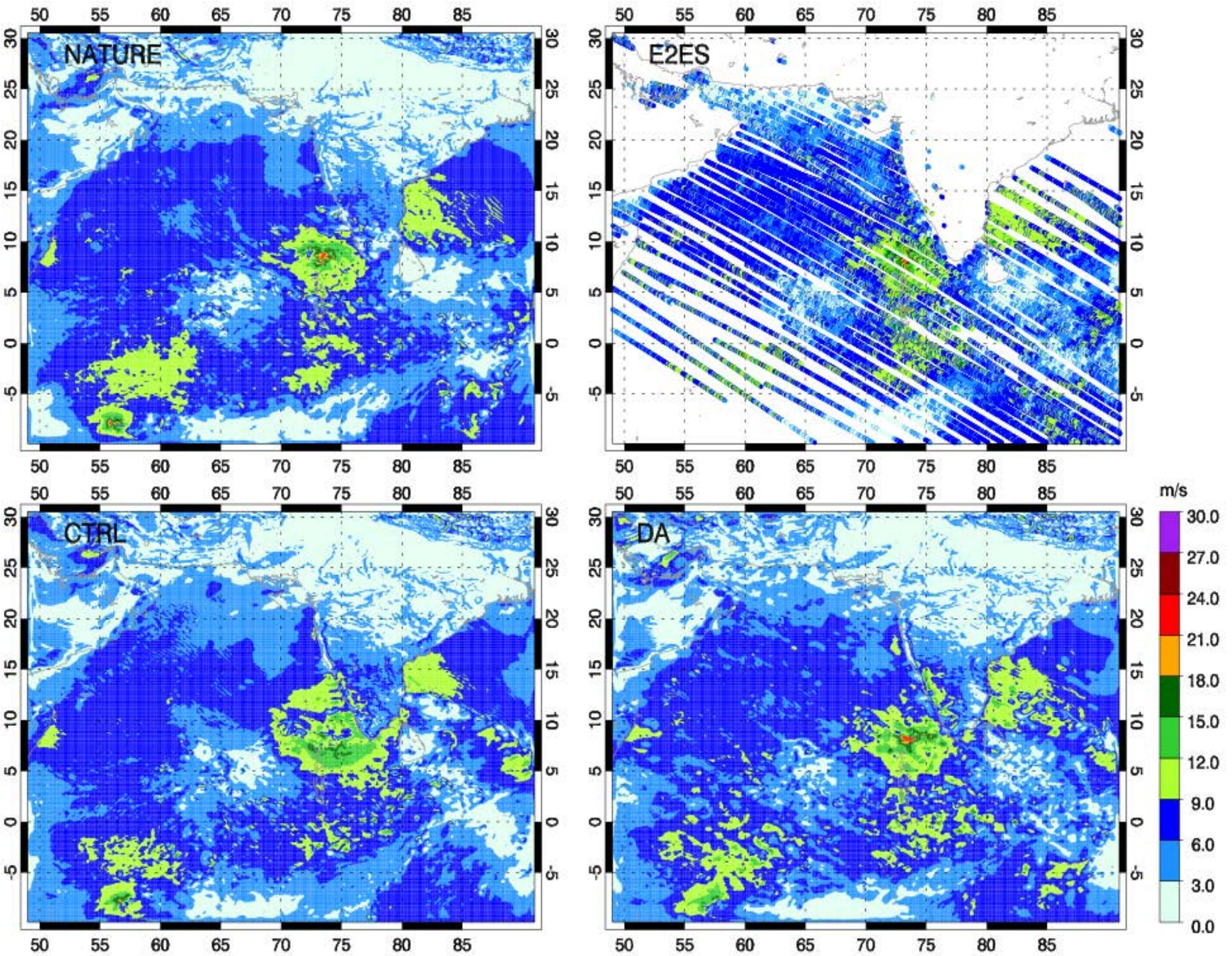
Nature run: WRF model simulation (9-km resolution) starts at 00 UTC 25 Nov 2011, initialized by ERA Interim analysis

CYGNSS E2ES wind: Generated from E2ES with WRF nature run files

CTRL: WRF model starts at 12 UTC 25 Nov 2011, initialized by GFS analysis

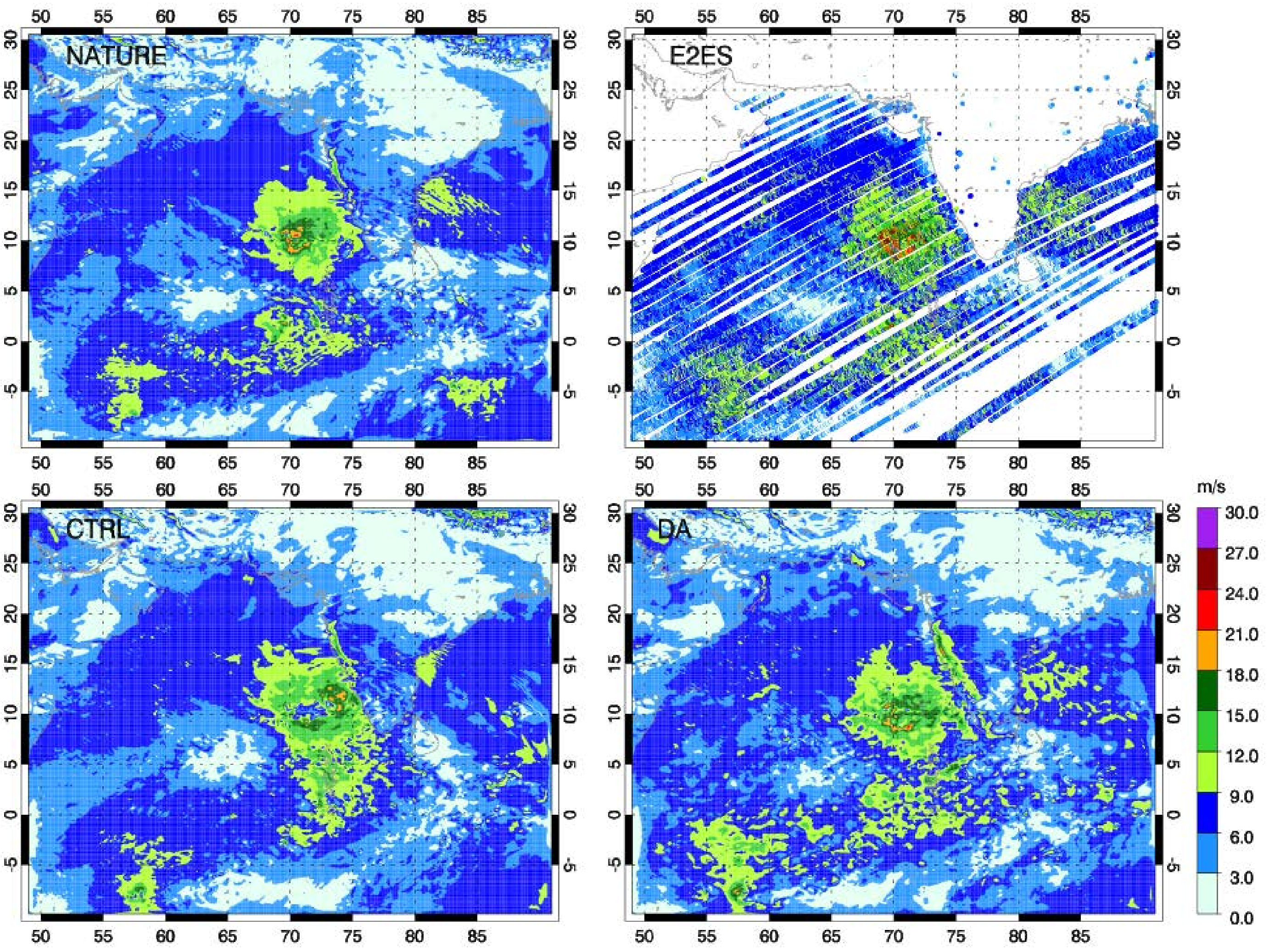
DA: Cycled assimilation of E2ES wind using CTRL as first guess

Analysis: 10-m Wind Speed at 15 UTC 2011-11-26



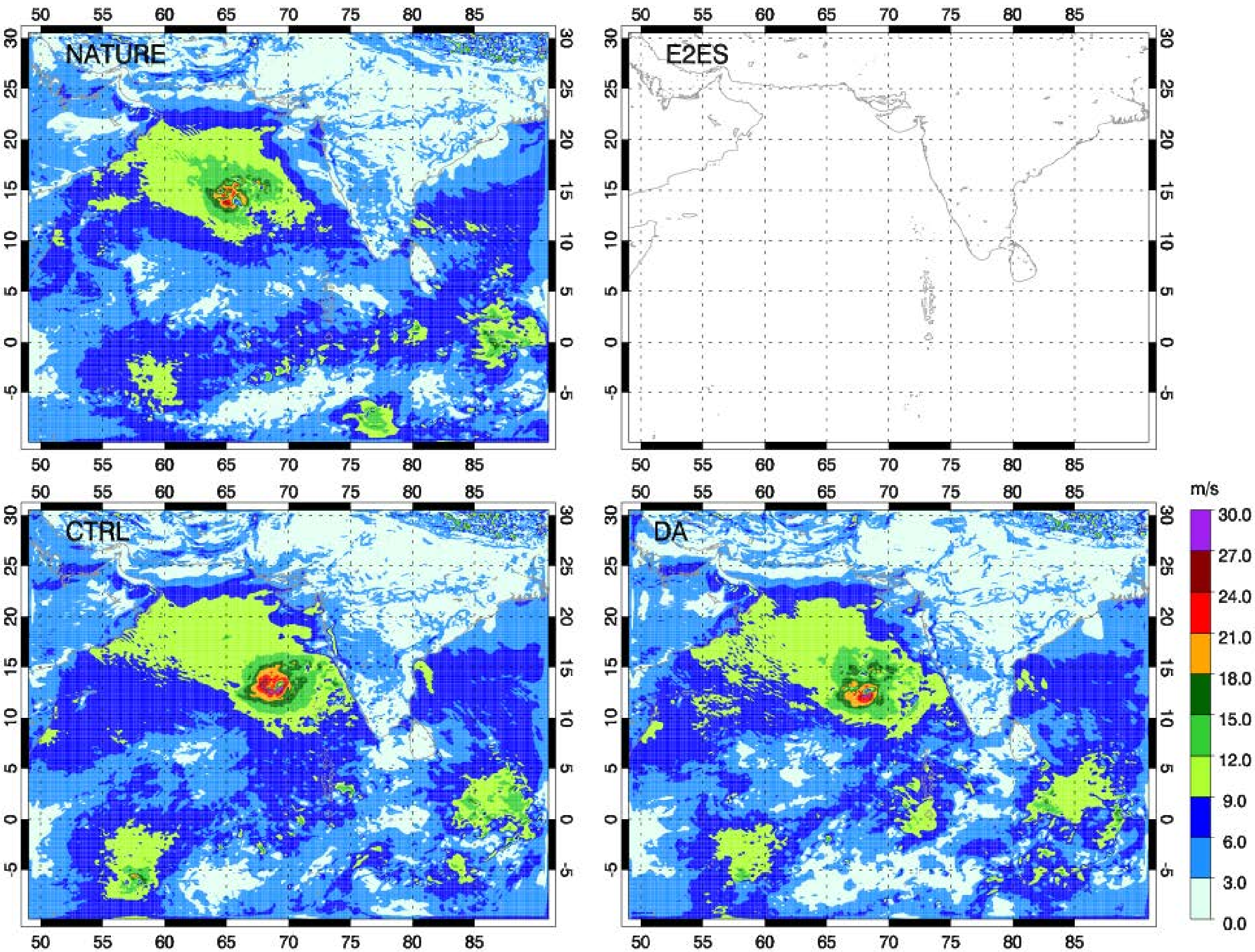
	Min	Aver	RMSE	Max
CTRL – NAT	-19.20	0.0197	1.97	12.93
NAT – NAT	-13.44	0.0021	1.93	11.93

Analysis: 10-m Wind Speed at 05 UTC 2011-11-27



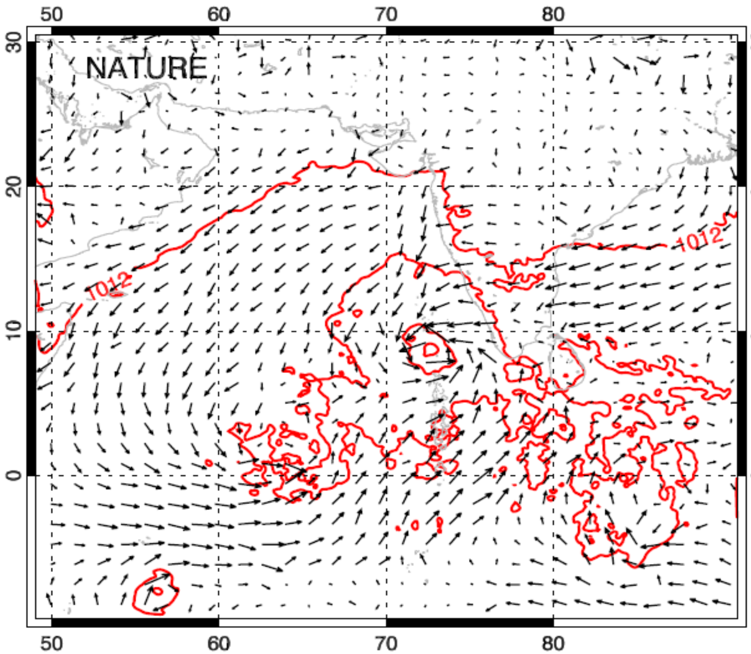
	Min	Aver	RMSE	Max
CTRL – NAT	-17.49	0.224	2.08	14.48
NAT – NAT	-17.24	0.219	2.04	14.07

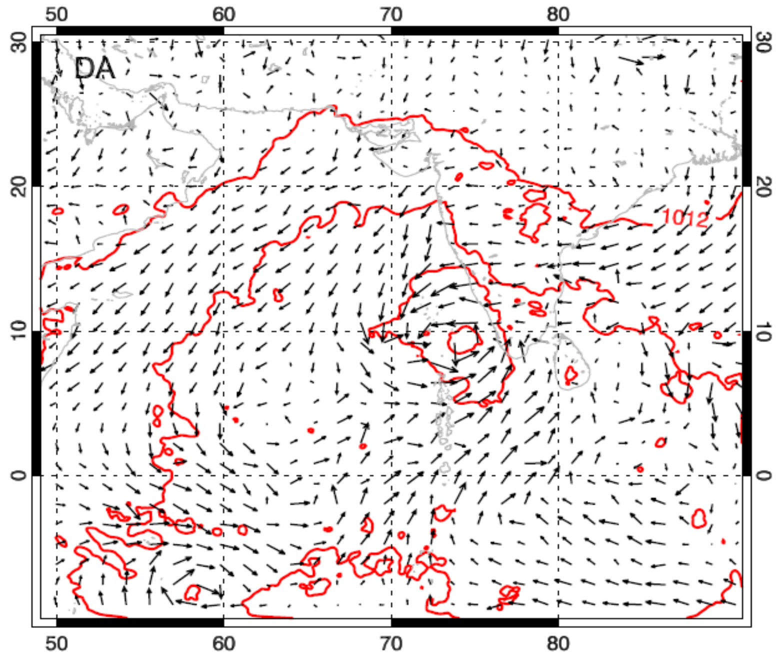
Forecast: 10-m Wind Speed at 15 UTC 2011-11-28

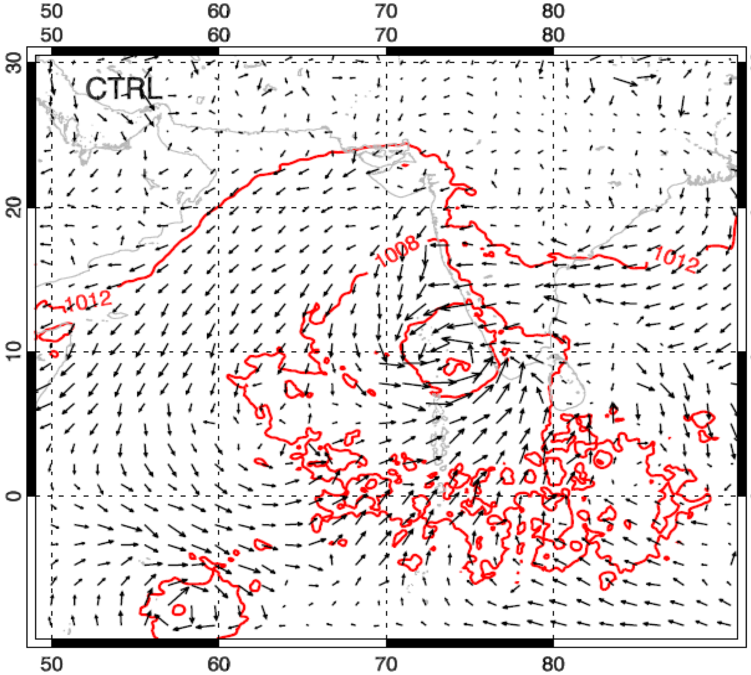


	Min	Aver	RMSE	Max
CTRL – NAT	-19.87	0.296	4.618	26.16
NAT – NAT	-12.87	0.0956	1.982	15.46

Analysis: SLP and wind vector at 18 UTC 2011-11-26

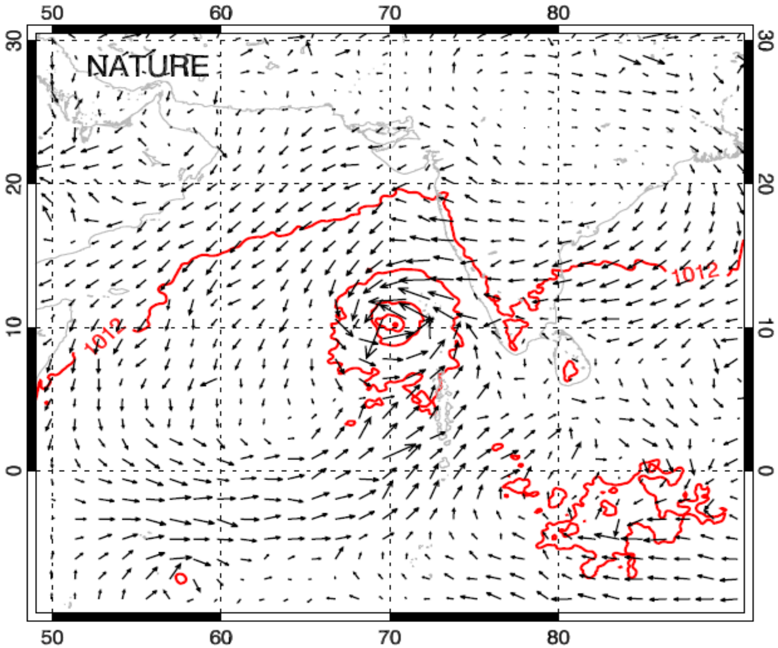


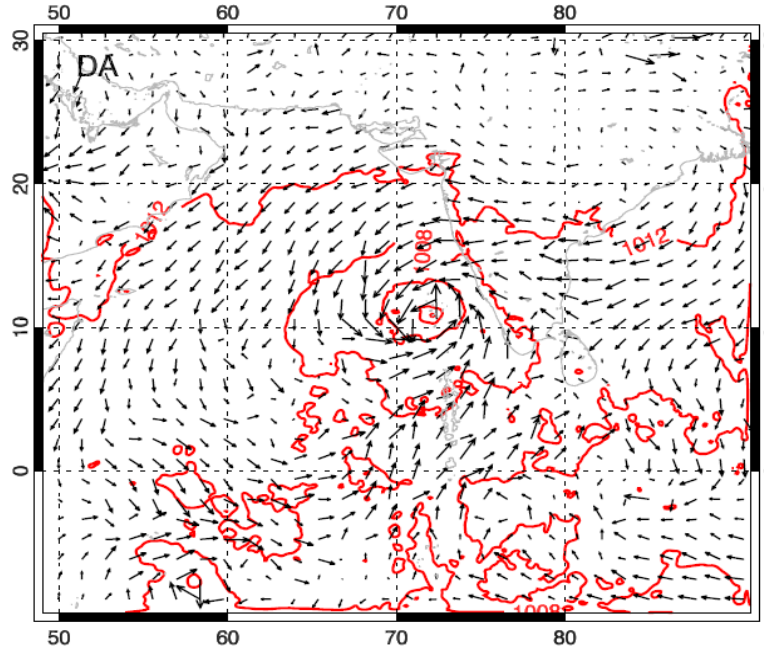


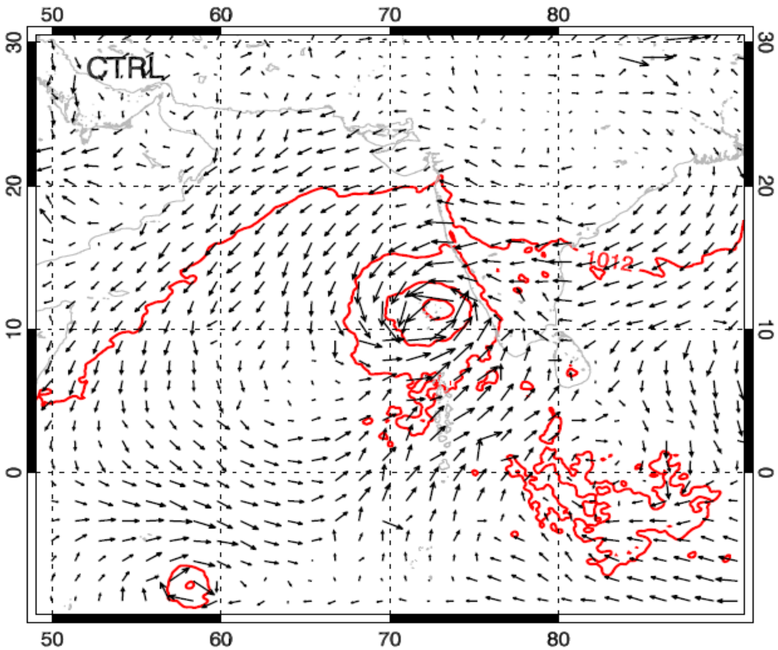


	NAT	DA	CTRL
Min SLP (hPa)	995	996	998
Max WSPD (m/s)	24.8	22.2	19.2

Analysis: SLP and wind vector at 06 UTC 2011-11-27

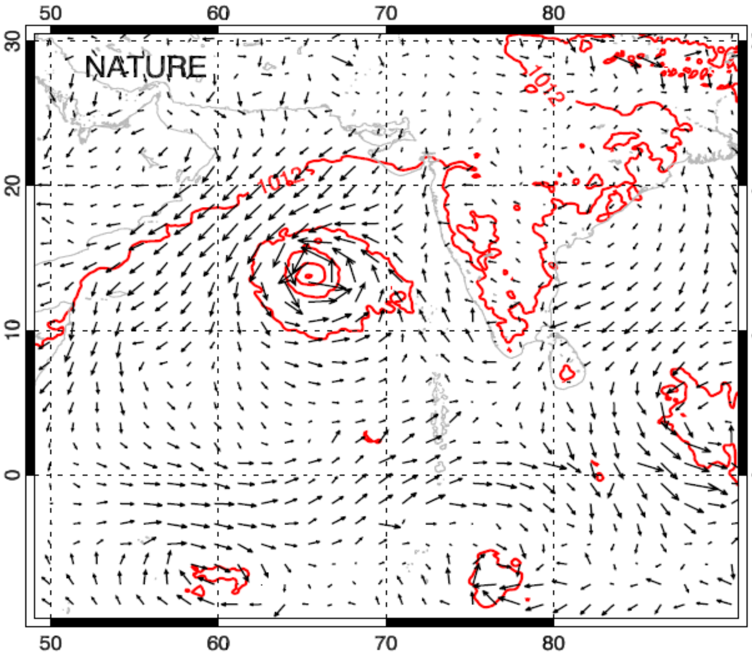


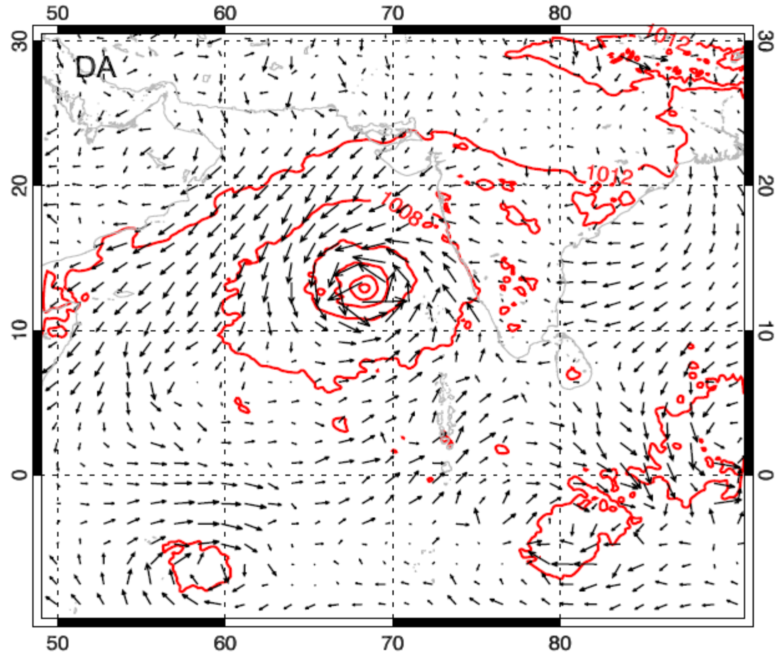


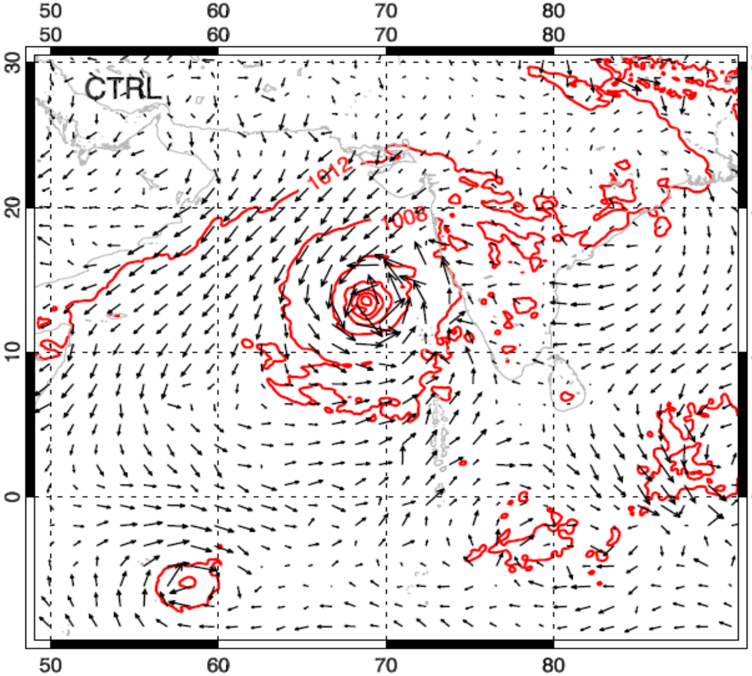


	NAT	DA	CTRL
Min SLP (hPa)	995	995	996
Max WSPD (m/s)	25.0	21.5	20.3

Forecast: SLP and wind vector at 18 UTC 2011-11-28

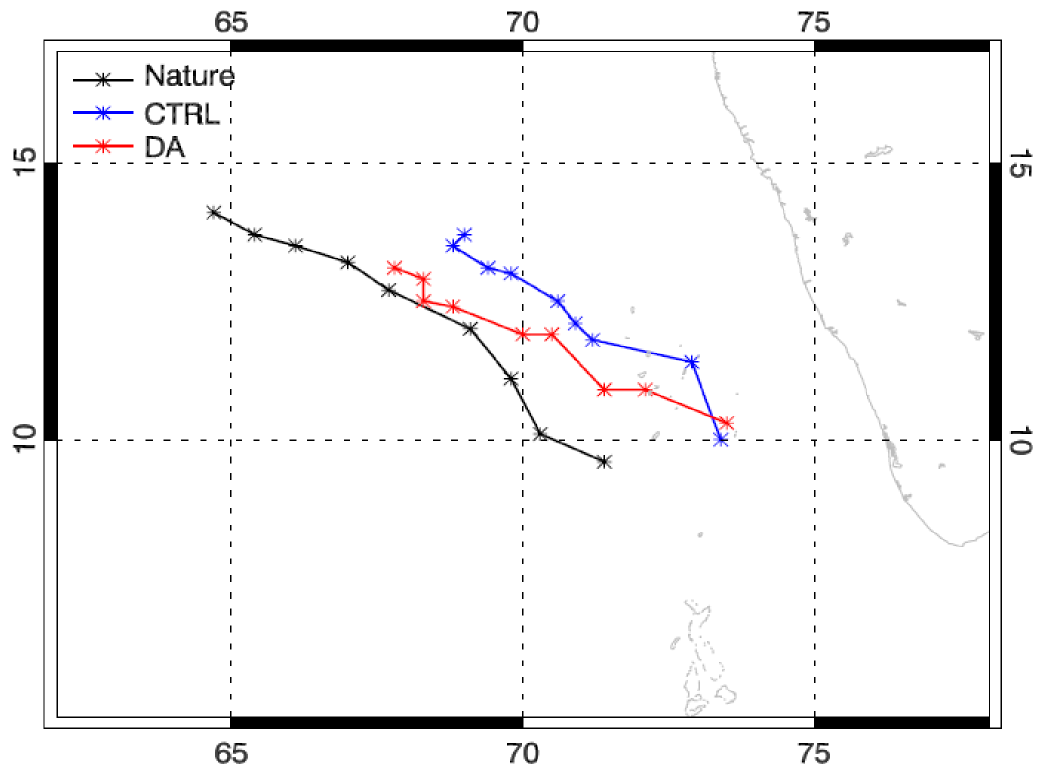






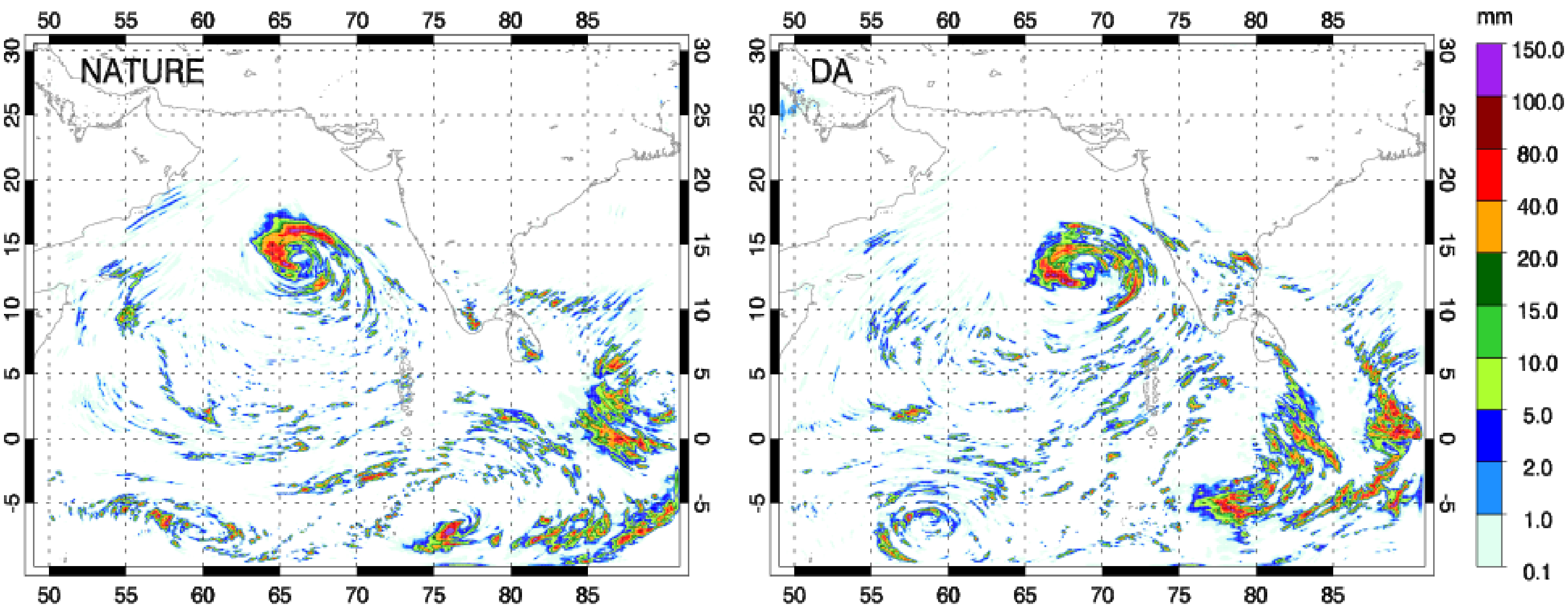
	NAT	DA	CTRL
Min SLP (hPa)	996	990	985
Max WSPD (m/s)	23.9	23.9	32.8

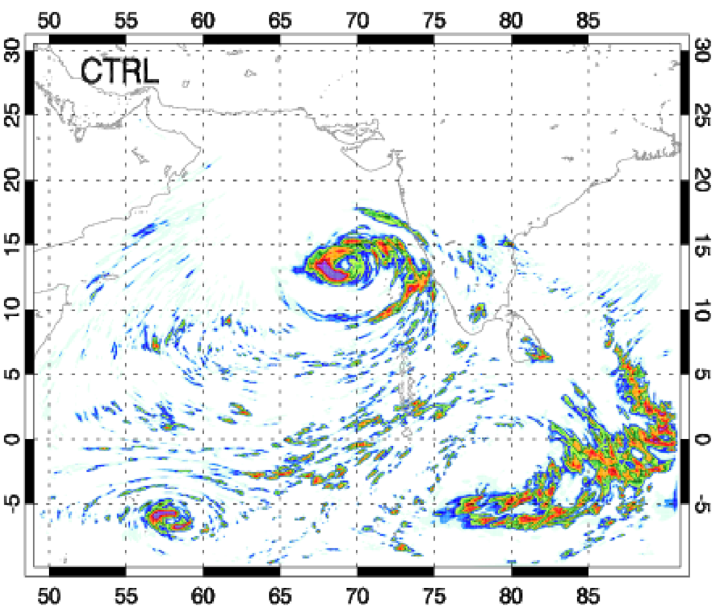
Storm Track
00 UTC 2011-11-27 to 00 UTC 2011-11-29



	00UTC 11/27	06UTC 11/27	12UTC 11/27	18UTC 11/27	00UTC 11/28	06UTC 11/28	12UTC 11/2	18UTC 11/2	00UTC 11/29
DA – NAT	243.1	216.2	176.3	152.9	265.5	214.7	263.3	326.5	353.4
CTRL – NAT	223.9	319.1	171.5	196.3	315.8	304.4	360.3	368.5	466.8

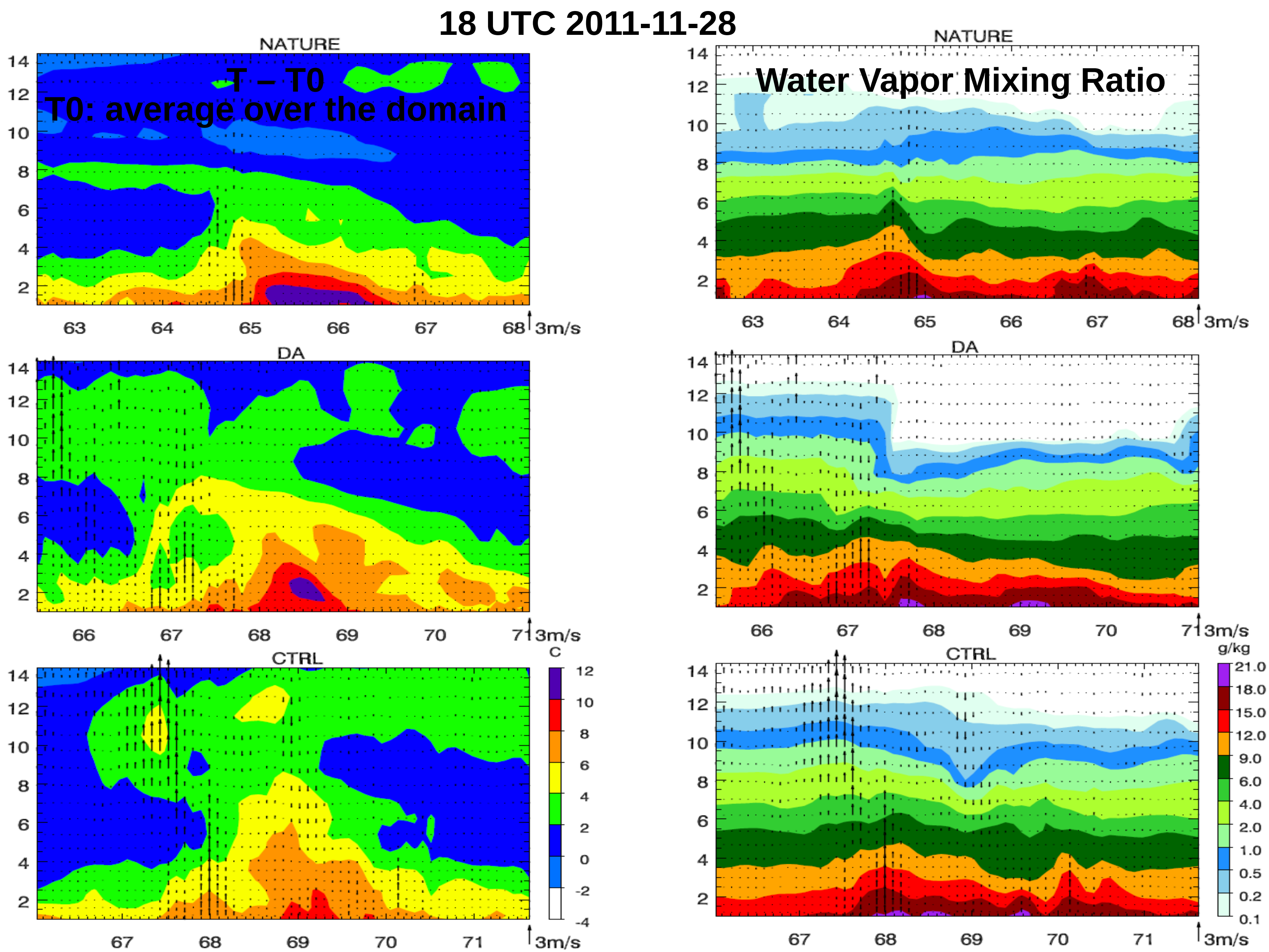
Forecast: 6-h Accumulate Rainfall 18 UTC 2011-11-28





Better Location and Intensity of Rainfall

Forecast: East-West Vertical Cross-section across Storm Center



NASA Project #2:

Demonstrating the value of CYGNSS for investigating relationships between wind-driven surface fluxes and tropical oceanic convection

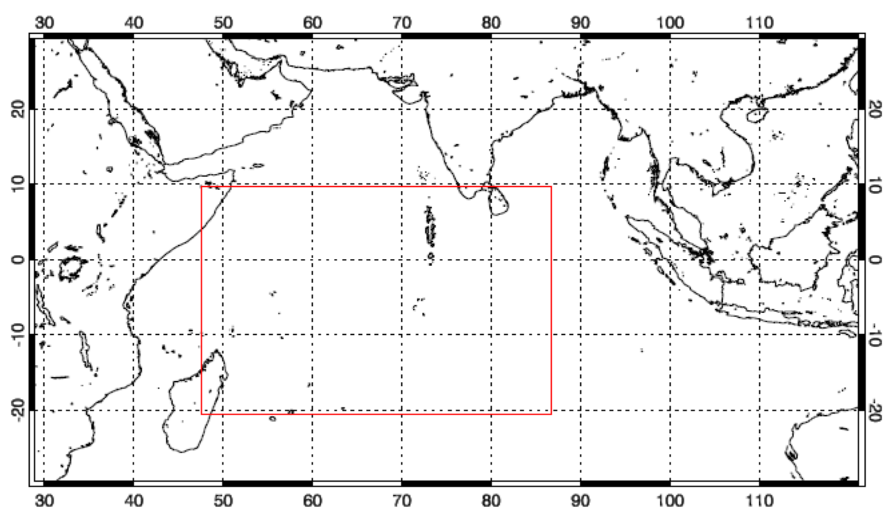
- Utilize CYGNSS data to study wind-precipitation-evaporation feedbacks
- Improve estimate of surface flux estimates in and near heavy convection
- Study the influence of wind-driven fluxes on convective development with assimilation of CYGNSS observation

Assimilation of Real CYGNSS Wind Speed

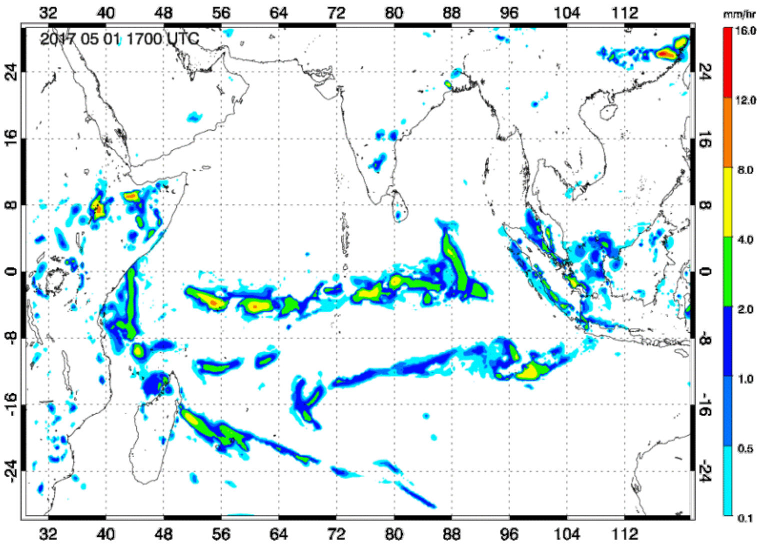
Data: CYGNSS L3 windspeed data between 00 and 02 UTC 1 May 2017

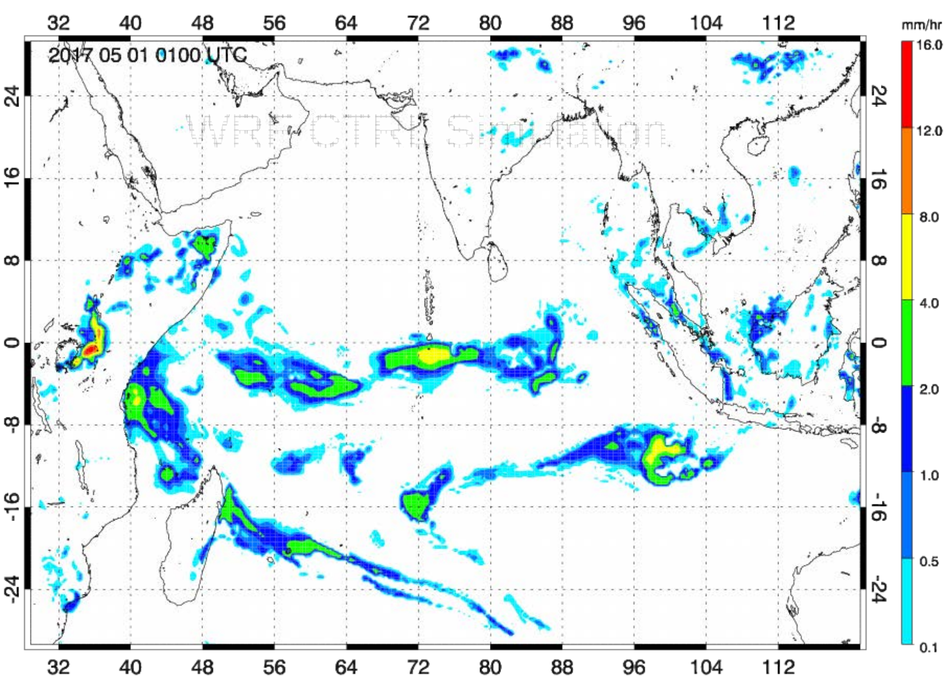
Control: WRF control simulation starts at 12 UTC 30 April 2017
2-nested domains (27 + 9 km)
20 ensemble members with different physics options and initial conditions

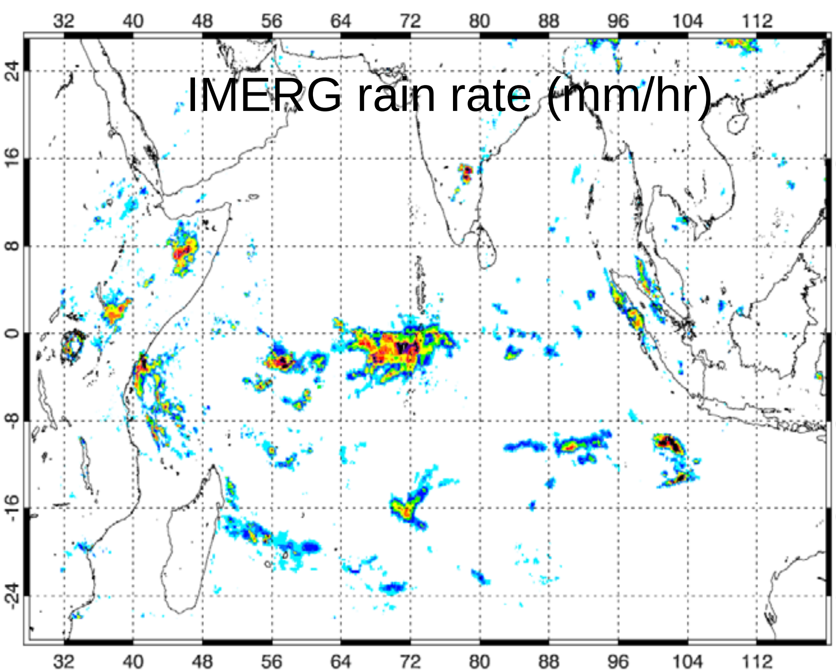
DA: Hybrid 3DVAR data assimilation
analysis time: 01 UTC 1 May 2017
assimilated into both domains
observational error: 2 m/s for windspeed < 20 m/s
10% for windspeed > 20 m/s



Tropical Convection In Central Indian Ocean
01 UTC 2017-05-01







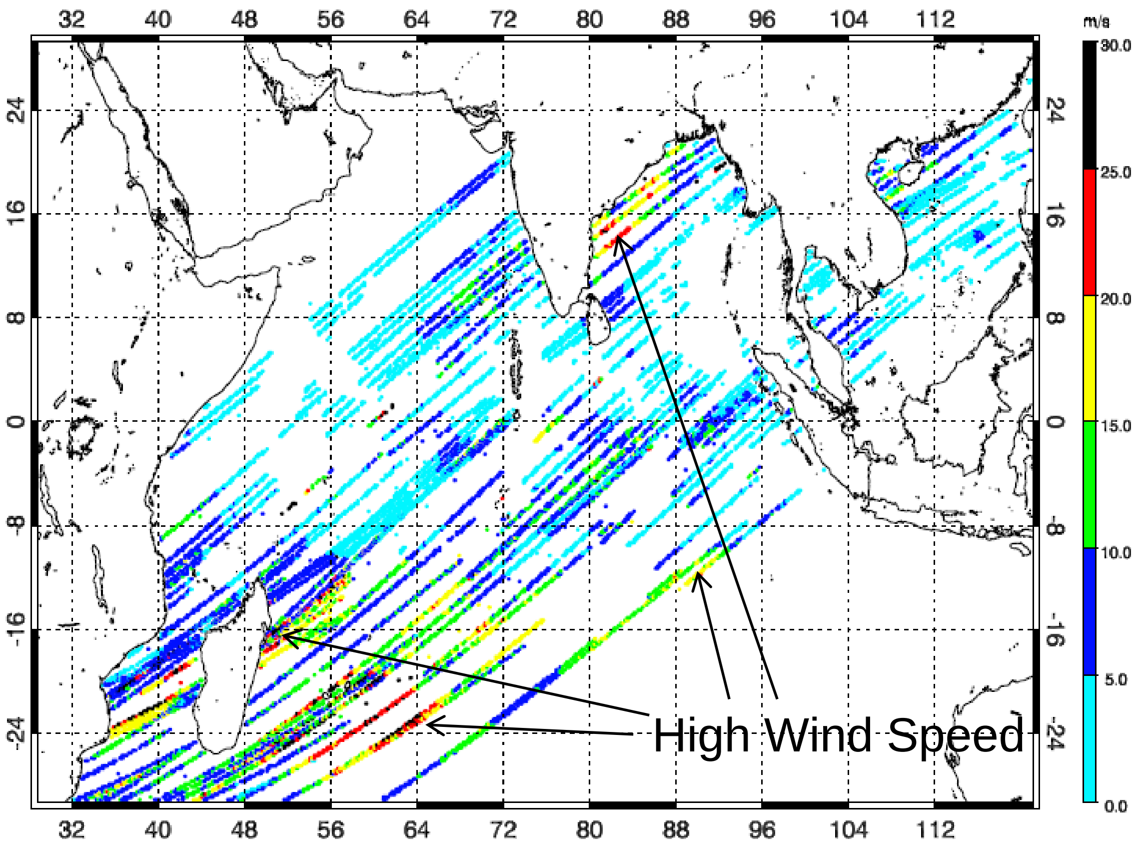
CYGNSS L3 WindSpeed 00-02 UTC 2017-05-01

CYGNSS L2 wind:

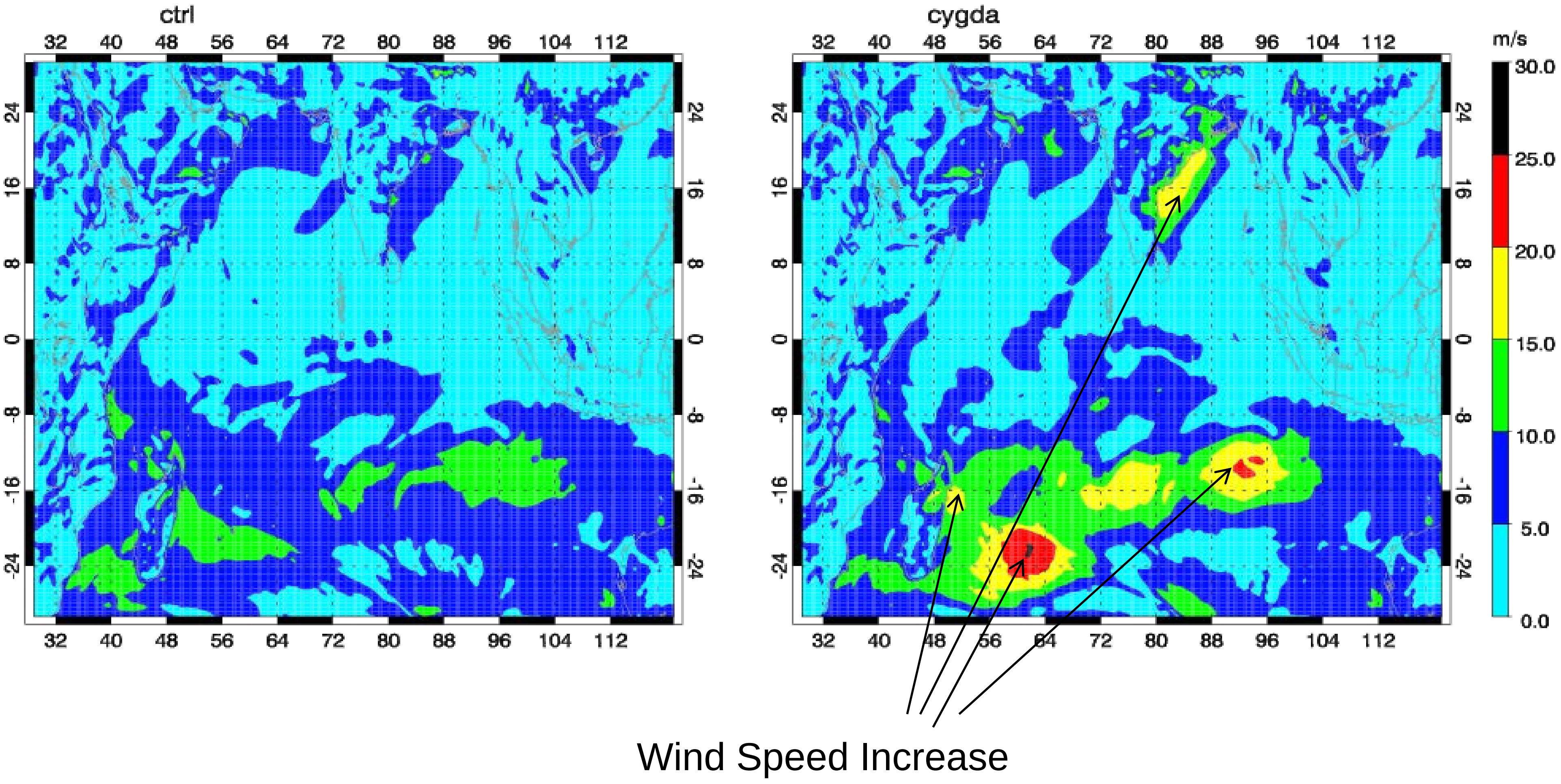
- Baseline product
- Time and location – measurement space (sensor-specific latitude, longitude, and time coordinates)

CYGNSS L3 wind:

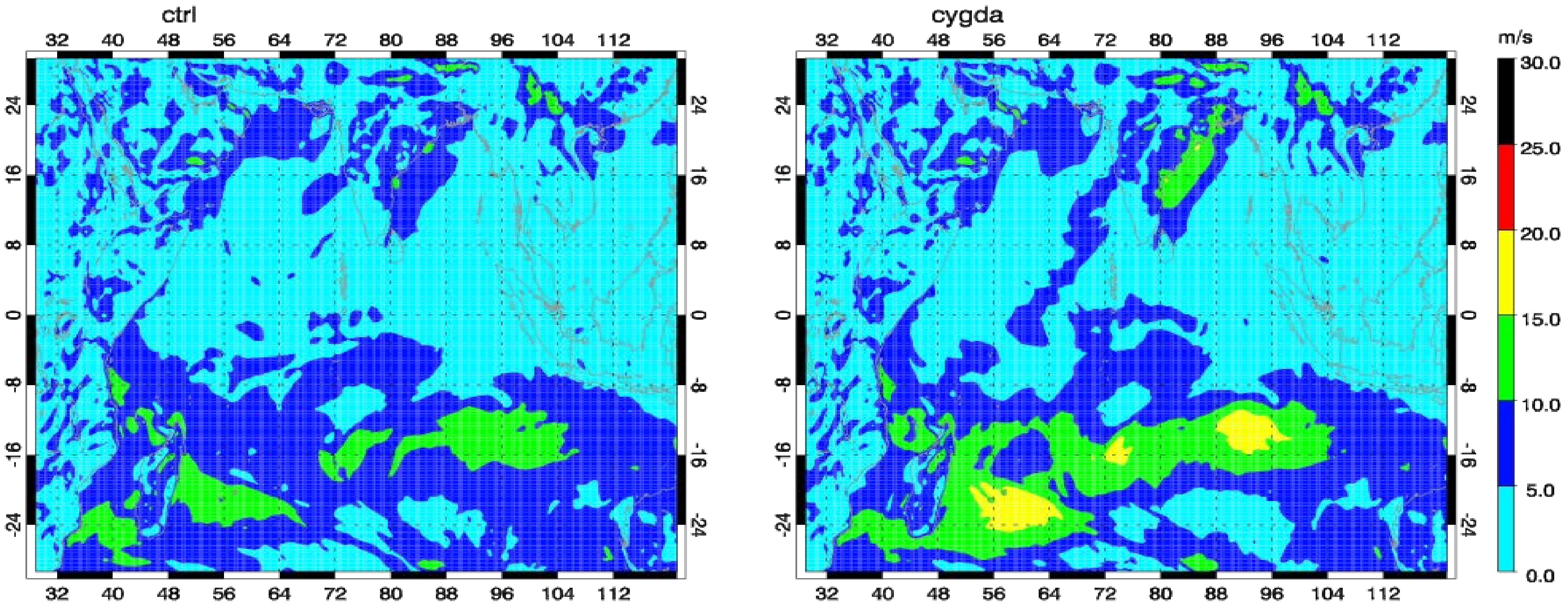
- Gridded wind in uniform latitude, longitude, and time
- Combines all 8 observatories x 4 bistatic radar channels = 32 measurements
- Statistics of each bin (number, mean value) and quality flags



10-m Wind Speed at 01 UTC 2017-05-01



10-m Wind Speed at 03 UTC 2017-05-01



Impact of wind speed assimilation is still apparent in 2 h forecast field

Discussion and Future Works

- Positive Impact has been found with hybrid 3DVAR assimilation of CYGNSS simulated for tropical storm, helping create an improved initial condition and better forecast – intensity, track, and precipitation

- Impact has been found in surface wind field with assimilation of real CYGNSS, which can last 6-12 hours

- Highlight the needs for improved quality of CYGNSS observation: Influence of CYGNSS data is greatly influenced by the data quality.

- CYGNSS DDM (magnitude and shape) is a function of ocean roughness. Further understanding on CYGNSS L1 DDM and its relationship with ocean surface roughness and how to obtain more accurate near-surface wind speed retrievals.